Embedding Evolution: Exploring Changes in Students' Conceptual Development, Beliefs, and Motivations in a Population Ecology Unit

A dissertation presented to
the faculty of
The Patton College of Education
of Ohio University

In partial fulfillment
of the requirements for the degree
Doctor of Philosophy

Nancy L. Rose
August 2012

© 2012 Nancy L. Rose. All Rights Reserved.
This dissertation titled
Embedding Evolution: Exploring Changes in Students' Conceptual Development, Beliefs, and Motivations in a Population Ecology Unit

by

NANCY L. ROSE

has been approved for

the Department of Teacher Education

and The Patton College of Education by

________________________________________
Ralph E. Martin
Professor Emeritus of Teacher Education

________________________________________
Renée A. Middleton
Dean, The Patton College of Education
Abstract

ROSE, NANCY L., Ph.D., August 2012, Curriculum and Instruction, Science Education

Embedding Evolution: Exploring Changes in Student's Conceptual Development, Beliefs, and Motivations in a Population Ecology Unit

Director of Dissertation: Ralph E. Martin

The purpose of this study was to explore student changes in conceptual development, epistemology, and motivations when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology. The two research problems were: 1) What changes are observed in student's conceptual development, epistemology, and motivations when there is explicit reflective discourse within a population ecology unit with embedded evolution?, and 2) In what ways does explicit reflection influence students' mental models within a population ecology unit with embedded evolution? This mixed-method, quasi-experimental study assessed two regular high school biology classes in a small, urban, Midwestern high school. Students in this study had not studied evolution within any formal chapters, but had been immersed in a curriculum with embedded evolution. The study was conducted over a four-week period in a population ecology unit near the beginning of second semester. Instruction emphasized basic conceptions in population ecology. Five key intervention activities included evolutionary concepts as part of an embedded curriculum. The independent variable was explicit reflective discourse with one or two intervention questions after completion of these activities. Data included pre- and posttest surveys measuring (a) evolutionary understanding of natural selection, (b) science beliefs, and (c) science
motivations. Written artifacts included (a) explanations to scenarios, (b) pre- and post-argument reflections revealing student's science beliefs and science motivations resultant from two argumentations, and (c) three, pre-, post-, and 6-week final concept maps constructed from 12 concepts. All data sources provided descriptive data. Conceptual change was interpreted from an ontological, epistemological, and motivational perspective. The experimental class receiving explicit reflective discourse showed greater overall increases in conceptual development. Students in both classes constructed teleological and proximate explanations. Overall, the experimental class gave greater numbers of evolutionary explanations. Scored propositions from concept maps showed a mixture of synthetic and scientific conceptions in both classes, however the experimental group showed greater scientific quality. Students in both classes exhibited direct-process ontology. Both classes had high degrees of epistemological and motivational commitments demonstrated by their engagement and subsequent improvements in conceptual development in both evolutionary and ecological conceptions.

Approved:_____________________________________________________________

Ralph E. Martin

Professor Emeritus of Teacher Education
Acknowledgments

I am fortunate to have found a supportive and understanding committee.

I first recognize Dr. Ralph E. Martin, as my chair, and my support. I appreciate all your encouragement, availability, professional advice, and necessary prompting. I acknowledge Dr. Jerry Johnson, as my methodologist who carefully and gently guided organization and analysis of the 'piles' of data. I especially appreciate dedication to me in this time of transition in your life.

I would also like to thank Dr. Henning for your unwavering support, extra time, and vigilance with regard to my writing. Lastly, I want you to know Dr. Franklin, that I recognize your professional expertise and appreciate all your willingness to serve on my committee without knowing me.
# Table of Contents

Abstract ............................................................................................................................... 3
Acknowledgments............................................................................................................... 5
List of Tables .................................................................................................................... 11
List of Figures ................................................................................................................... 12
Chapter 1: Learning Evolution.......................................................................................... 13
  Study Background ......................................................................................................... 15
  The Problem .................................................................................................................. 15
  Religious beliefs and acceptance. ................................................................................. 16
    Lack of nature of science knowledge. .................................................................. 17
    Alternative conceptions. ......................................................................................... 18
  Pedagogy and curriculum. ........................................................................................ 19
Conceptual Framework ................................................................................................. 20
Study Purpose ............................................................................................................... 24
Research Questions ....................................................................................................... 25
Significance of this Study ............................................................................................. 25
Synopsis of Methodology ............................................................................................. 27
Study Limitations .......................................................................................................... 27
Researcher Perspectives ................................................................................................. 29
Definitions of Key Terms ............................................................................................. 31
Chapter 2: Literature Review ............................................................................................ 35
  Learning Science and Conceptual Change ................................................................. 35
    Learning science from a socio-cultural perspective ................................................. 36
    Learning science from a cognitive perspective ....................................................... 37
Conceptual Change from a Psychological Perspective .................................................... 39
Developmental perspectives ......................................................................................... 39
Framework theory ........................................................................................................ 41
  Coherent frameworks and conceptual change in evolution ....................................... 44
Phenomenological primitives (p-prims) ......................................................................... 46
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Ecology and Evolution Standards</td>
<td>78</td>
</tr>
<tr>
<td>Table 2</td>
<td>Summary of Unit Progression</td>
<td>93</td>
</tr>
<tr>
<td>Table 3</td>
<td>Measured Epistemological Dimensions</td>
<td>96</td>
</tr>
<tr>
<td>Table 4</td>
<td>Explanation Tasks</td>
<td>102</td>
</tr>
<tr>
<td>Table 5</td>
<td>Concept Similarity Task</td>
<td>105</td>
</tr>
<tr>
<td>Table 6</td>
<td>Intervention Questions for Reflective Discourse</td>
<td>112</td>
</tr>
<tr>
<td>Table 7</td>
<td>Intervention Summary</td>
<td>114</td>
</tr>
<tr>
<td>Table 8</td>
<td>Summary of Research Methodology</td>
<td>125</td>
</tr>
<tr>
<td>Table 9</td>
<td>Survey Mean Score Totals</td>
<td>127</td>
</tr>
<tr>
<td>Table 10</td>
<td>SEB Dimensions</td>
<td>129</td>
</tr>
<tr>
<td>Table 11</td>
<td>SMQII Components</td>
<td>130</td>
</tr>
<tr>
<td>Table 12</td>
<td>Individual Student Explanations Results</td>
<td>133</td>
</tr>
<tr>
<td>Table 13</td>
<td>Student Explanations for Adaptations</td>
<td>134</td>
</tr>
<tr>
<td>Table 14</td>
<td>Student Explanation Progressions</td>
<td>135</td>
</tr>
<tr>
<td>Table 15</td>
<td>Class Conceptual Status</td>
<td>139</td>
</tr>
<tr>
<td>Table 16</td>
<td>Class Epistemological Status</td>
<td>141</td>
</tr>
<tr>
<td>Table 17</td>
<td>Class Motivational Status</td>
<td>142</td>
</tr>
<tr>
<td>Table 18</td>
<td>Individual Student Beliefs and Motivations Status</td>
<td>143</td>
</tr>
<tr>
<td>Table 19</td>
<td>Student Proposition Scoring</td>
<td>145</td>
</tr>
<tr>
<td>Table 20</td>
<td>Concept Map Scoring Results</td>
<td>146</td>
</tr>
<tr>
<td>Table 21</td>
<td>Total Synthetic and Scientific Propositions</td>
<td>147</td>
</tr>
<tr>
<td>Table 22</td>
<td>Total Scientific and Evolutionary Propositions</td>
<td>148</td>
</tr>
<tr>
<td>Table 23</td>
<td>Number of Natural Selection Propositions</td>
<td>151</td>
</tr>
<tr>
<td>Table 24</td>
<td>Number of Identified Alternate Conceptions</td>
<td>152</td>
</tr>
<tr>
<td>Table 25</td>
<td>Student Supposition Progressions</td>
<td>153</td>
</tr>
<tr>
<td>Table 26</td>
<td>Student Concept Map Structures</td>
<td>154</td>
</tr>
<tr>
<td>Table 27</td>
<td>Unit Assessment Scores Summary</td>
<td>158</td>
</tr>
<tr>
<td>Table 28</td>
<td>Class Summary of Explanations</td>
<td>160</td>
</tr>
<tr>
<td>Table 29</td>
<td>Score Summaries-Science Beliefs and Motivations</td>
<td>162</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Pedagogical Model for Conceptual Change</td>
<td>76</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Data Collection Sequence</td>
<td>92</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Student Cognitive-Associative Map</td>
<td>155</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Student H-Map</td>
<td>155</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Student Final C-Map</td>
<td>156</td>
</tr>
</tbody>
</table>
Chapter 1: Learning Evolution

Evolution is considered a dynamic systems process and one of several general domains that intersect and interact to form the framework of biology (Scheiner, 2010). Evolution serves as a core idea and buttress for national and state content standards for student learning in life science (National Research Council [NRC], 2011; Ohio Department of Education [ODE], 2002). National Academy of Science's, NAS, (1998) book, Teaching about Evolution and the Nature of Science, assert that evolution is a uniting scientific paradigm for biology and that the history of life on Earth explains the origins and relationship of every organism living and in the past.

Knowledge about evolution is considered essential knowledge for the development of scientific literacy, because of its importance for decision making concerning environmental and health issues. Personal issues, like antibiotic resistance, safety genetically altered and modified foods, or having genetic testing have evolution underpinnings. These concepts need to be understood by the general public in order to recognize and weigh the benefits and risks (The American Association for the Advancement of Science [AAAS], 1993). In his book, Endless Forms Most Beautiful (2005), Carroll, warrants his claim for placing evolution in the center of teaching biology and contends that "The importance of evolutionary biology is far more than mere philosophy. The fate of the endless forms of Nature, including humans, depends on a broader understanding of human impacts on evolution" (p. 283).

Evolution is an important domain in biology, and its centrality should be made explicit in the biology curriculum. Catley (2006) echoes these sentiments and views
evolutionary understanding as a prerequisite for saving our planet from ecological collapse when she asserted that "The sense of humility gained through an appreciation of the kinship of all life is a vitally important component in nurturing a stewardship ethic..." (p. 781).

There are numerous statements, positions, and literary assertions that posit evolution as a major organizing theme for textbooks and biology curricula (Alles, 2001; Flammer, 2006; Nehm, Kim, Sheppard, 2009; Nickels, Nelson, & Beards, 1996). Evolution, however, is traditionally taught as discreet units in two or three chapters near the middle or end of the school year in a typical high-school biology class. There is no literature investigating student learning when evolution is embedded within the curriculum and given perspicuous attention outside formal evolution chapters. This study explores student learning when evolution concepts are embedded and given this attention through explicit reflection. Student conceptual development in evolution, as well as scientific beliefs and motivations are documented throughout an ecology unit on populations in two, general, high-school biology classes.

This chapter begins with an overview of the background and context describing some of the factors contributing to the problems of teaching and learning of evolution in K-12 and college classrooms. Constructs that serve as barriers associated with these problematic factors are introduced to frame this study. Included in this chapter are the focused research questions, a brief discussion of the research approach, limitations, significance of this study, and definitions of key terminology.
Study Background

Despite evolution's significance to understanding biology and its importance for development of scientific literacy, evolution can be a problematic idea and issue for some teachers and communities throughout the United States. Numerous quantitative, qualitative, and mixed methodologies have been employed in science-education studies focusing on the teaching and learning of evolution over the last 30 years (Brumby, 1984; Lawson & Worsnop, 1992; Moore, Froehle, Kiernan, & Greenwald, 2006). This body of scholarship has produced much knowledge about students’ and teachers' scientific and personal epistemologies, conceptions about evolution, and instructional practices conducted in many academic contexts from primary grades through college. Polemic disputes can juxtapose evolutionary theory with religious beliefs creating angst within communities and schools. Legal battles began in the landmark case, the Scopes Monkey Trial, and the last decade ushered in 15 ongoing and decided cases (National Center for Science Education, [NCSE], 2010) throughout the United States.

The Problem

Evolution can be a contentious, emotional, and controversial issue in some high school biology classes, even though it is a linchpin for understanding biological science. There are many factors that contribute to the problems surrounding the teaching and learning of evolution in some schools and communities. Research indicates that the teaching and learning of evolution can be problematic in several ways: a) evolution may be viewed as anti-religious and controversial, b) evolution may not be accepted as a well-
supported theory, c) there are misconceptions in evolutionary reasoning and; d) there are pedagogy and curricular issues affecting how evolution is taught in the classroom (Smith, 2010).

It is essential to discuss the factors contributing to the problem, in order to understand the significance. Factors contributing to problems with the teaching and learning of evolution are numerous and diverse. Religious beliefs, lack of understanding of the nature of science, deeply entrenched alternative conceptions, teaching, and the curriculum can be impediments and barriers to engagement in evolutionary reasoning. These influences will be briefly described to help frame this study.

**Religious beliefs and acceptance.**

Students' religious beliefs may affect their acceptance of evolution as a valid theory. Research has supported the assertion that commitment to religious beliefs may play a role in students' beliefs of evolutionary theory (Gregory, 2009; Lawson & Worsnop, 1992). In addition, research suggests there is a strong connection between students' positions regarding the theory of evolution and their religious affiliation and understanding of theories (Dagher & BouJaoude, 1997, 2005). Literature also hints that students may not accept evolutionary theory due to beliefs that evolution conflicts with their personal beliefs (Dagher & BouJaoude; Southerland, Sinatra, & Matthews, 2004), while in other similar studies college students found evolution disheartening (Brem, Ranney, & Schindel, 2003). Literature suggests students with firm religious beliefs may have a reduced willingness to engage, learn evolutionary theory, and/or reject this scientific concept. Students' religious beliefs have been associated with their willingness
to understand and accept evolutionary concepts. This creates problematic contexts in some classrooms.

**Lack of nature of science knowledge.**

Controversy may arise because there is a blurring of boundaries between what constitutes scientific knowledge, how scientists gather and validate knowledge empirically, and construction of everyday epistemic beliefs based on common experiences and/or religious beliefs. The validity of any scientific theory depends upon the establishment of criteria or evidence to judge a claim and its explanatory and predictive utility (Carey & Smith, 1993; Kuhn, 1991; Matthews, 1994). Student understanding of the nature of science (NOS) and development of accurate scientific beliefs may contribute to better learning of science content (Hammer, 1994; Schommer, 1993; Smith, Maclin, Houghton, & Hennessey, 2000).

One of the first studies to link understanding the NOS to acceptance of evolution as a valid theory was conducted by Johnson and Peebles (1987). These researchers found college students' levels of acceptance of evolution theory corresponded to their limits of understanding of the NOS. The research of Moore, Froehle, Kiernan, and Greenwald (2006) reported students not only had misconceptions, but they also thought evolution is full of conflicts and contradictions. Their study found that some students thought a theory is a hunch. These common science beliefs contribute to faulty reasoning, because students do not understand the NOS and how scientific knowledge is constructed.

Literature reveals that many problems associated with alternative, inaccurate conceptions or misconceptions (Bishop & Anderson, 1990; Brumby, 1984; Gregory,
These conceptions continue beyond high school into college, may be attributed to lack of attention on and/or knowledge of the NOS.

**Alternative conceptions.**

Alternative conceptions and everyday scientific beliefs abound within classrooms, in media, and among the general public, despite persistent and diligent efforts by researchers, psychologists, and educators to inform and advance science education to improve scientific literacy. Students consistently demonstrate that they have misconceptions or alternative, inaccurate conceptions in evolutionary constructs. High school and college students have misconceptions about natural selection that include origin and maintenance of traits (needs, use and disuse, adaptation) variations, evolution of species (Bishop & Anderson, 1990; Brumby, 1984; Gregory, 2009).

Student explanations may reveal deeply entrenched and tightly woven intuitive constructs that are meaningful in common, everyday science explanations, but not acceptable as school science (Bishop & Anderson, 1990; Brumby, 1984; Gregory, 2009; Haldén, 1988; Kampourikas & Zogza, 2008). For instance, Bishop and Anderson reported over 50% of the college students they tested had naive conceptions of natural selection and attribute this to the simplicity and logic of naive ideas. Halldén (1988) described college students' learning on the origin of species using pre- and post essays. After seven weeks of instruction, students had difficulties distinguishing mutation significance at the species and population levels. More recently, Kampourakis & Zogza (2008) reported that secondary students lack important evolutionary knowledge in concepts such as common descent and natural selection. While many studies focused on
identifying student misconceptions and pedagogical approaches that would lead to conceptual change (Jensen & Finley, 1996; Nickels, Nelson, Beard, 1996; Scharmann, 1990), several additional studies identified pedagogy and curriculum as factors contributing to this dilemma of evolution in the classroom (Alters & Nelson, 2002; Nehm et al, 2008; Padian, 2008).

**Pedagogy and curriculum.**

Another contributing factor associated with teaching and learning of evolution has to do with the amount of productive teaching time spent on the standards within the lesson or curriculum. Teachers may not be teaching evolution or may be minimalizing the content of the evolution units for several reasons. Teachers can compromise pedagogy relating to evolution and influence their students' learning and understanding of evolution. In this interview a teacher said, "We just don't have time to teach evolution. So we choose not to" (Griffith & Brem, 2004, p. 799). Some teachers may use standards to reduce external pressures (Donnelly & Boone, 2007; Goldston & Kyzer, 2009; Moore, Froehle, Kiernan, & Greenwald, 2006). Empirical research has revealed that teachers tended to rely more on the textbook and standards to reduce external pressures, from students, parents, and/or community. Teachers have been found to depend on texts and standards (Donnelly and Boone 2004; Fowler & Meisels, 2010) as authority and justification for teaching evolution (Goldston & Kyzer, 2009; Moore, Froehle, Kiernan, & Greenwald, 2006). Moreover, recent literature calls into question the accountability and pedagogical soundness in some of the most popular texts (Catley & Novick, 2008; Nehm et al., 2008).
Evolution can be problematic in classrooms and many factors contribute to this dilemma. Multiple factors can influence student learning of evolution. However, students must develop a more scientific understanding of evolution as an essential core science idea (NAS, 2011) and progress toward the goal of scientific literacy. This study focused on student changes in conceptual development, science beliefs, and motivations when perspicuous attention is given to evolution concepts embedded in a unit on population ecology. Student learning was interpreted from an ontological, epistemological, and motivational (multidimensional) perspective (Duit & Treagust, 2003; Treagust & Duit, 2008; Venville & Treagust, 1998; Tyson, Venville, Harrison, & Treagust, 1997).

**Conceptual Framework**

Students' alternative conceptions, epistemological beliefs, and motivations all contribute to the challenging dynamics of learning evolutionary theory in the classroom. Learning is not just a cognitive or individual activity, but learning science is also social activity (Leach & Scott, 2003). It comes from the construction of meaning from experiences, a constructivist position. Formal science learning is more than adding to existing knowledge. Students' experiences, personal beliefs and characteristics, and culture all contribute to learning in the classroom.

Understanding evolution, like other concepts in science, generally includes more than just adding on to students' current knowledge. Learning encompasses deep engagement, active revision, and restructuring conceptions into more scientific mental models (Chi, 2008; Chinn & Malhotra, 2002; Vosniadou & Brewer, 1987). This type of learning in science is synonymous with conceptual change (Duit & Treagust, 2003).
Prior to the 1990's, students were considered more like scientists, logical and rational. Science teachers, as authorities, gave student new information to create dissatisfaction with existing alternate conceptions. Students would see the 'error in their thinking' and change conceptually. Now, conceptual change is known to be influenced, not only by cognitive dissonance but beliefs and motivations, as well as contextual factors (Duit & Treagust, 2003, Pintrich, Marx, & Boyle, 1993; Sinatra, 2005; Treagust & Duit, 2008). The importance of ascertaining students' existing conceptions drives constructivist pedagogy in the classroom.

Students bring common, everyday science conceptions to class and these conceptions can be quite different from scientific conceptions (Scott, Asoko, & Leach, 2007). Researchers have recognized alternative, everyday science conceptions as barriers to the development of evolutionary reasoning. To illustrate, Stephanie, when questioned about speciation responded, "I just don't think that we evolved from fish. Because then there wouldn't be any fish. They would all be evolved" (Demastes, Good, & Peebles, 1995, p. 651). This short discourse shows that Stephanie did not understand the process of evolution, geographic isolation, and deep time. She also held the alternative conception that evolving means turning into another species. This type of misconception is commonly advanced in popular media when describing humans as evolving from chimpanzees. Conceptual change refers to the accommodation and restructuring of existing alternative, everyday science conceptions to more scientific conceptions.

Students' pre-existing epistemological frameworks which are important influences on how each student perceives evidence and inferences in evolutionary theory as valid
and credible (Dole & Sinatra, 1998; Evans, Legare, & Rosengren, 2011; Pintrich, Marx, & Boyle, 1993; Sinatra, Brem, & Evans, 2008). Students with inaccurate scientific epistemologies may lack active engagement in learning. In this student comment, "Although evidences mainly from embryology, biochemistry, and paleontology are in favor of the theory of evolution, yet, I believe they are not evidence enough to the truth of such a theory" (Dagher & BouJaoude, 1997, p. 435). This student rejects evolution on the basis that it is problematic from a science standpoint, which indicates the student does not understand the nature of scientific theory and the distinctions between religious beliefs and scientific beliefs. Yet in any classroom setting, a student might insist, 'I don't understand why we have to do this. Why can't you just tell us the answer? There is only one answer!' This example reveals much about the students' personal beliefs about the nature of knowledge and learning (Hofer & Pintrich, 1997).

These examples illustrate how common, everyday science beliefs can have profound effects on their learning approaches and achievement outcomes. Research in the learning of evolutionary theory reveals students' epistemologies are often more predictive of their acceptance of scientific theories than their knowledge of concepts used as warrants in those theories (Hofer, Lam, & DeLisi, 2011; Sinatra, Southerland, McConaughy, & Demastes, 2003). Another important construct influencing learning is the affective/social characteristics of the students in the classroom.

Students' personal characteristics like attitude, intrinsic motivation, and self-efficacy can have a profound effect on conceptual change (Koballa & Glynn, 2007; Sinatra & Mason, 2008). Students' level of comfort, security, and interest enhance
students' potential for imagination and learning (Dagher & BouJaoude, 2005).

Motivations, like personal relevance and grades can promote engagement and participation in learning (Dole and Sinatra, 1998; Koballa & Glynn, 2007; Palmer, 2005).

The following example is just one situation in which the motivational variable, anxiety, can manifest in the classroom, when debating the issue of inclusion of religious interpretation in a college evolution class. This response is from a student interview and the prompt is whether evolution and creationism should be taught side-by-side: "You can't just force one idea without showing an alternative solution. It is up to the student to decide for himself what he puts his/her faith in, science or religion," (Brem, Ranney, & Schindel, 2003, p. 195). From this portion of the artifact, you can clearly sense the feelings and beliefs this college student expresses. Students with strong creation beliefs are not likely to engage in deep learning, unless they understand the clear distinction between religion and science. Not to acknowledge or attend to motivational constructs involved with the teaching of evolution is not teaching for conceptual change, especially in a community that endorses creationism.

Alternative conceptions, science beliefs, and motivations are important variables in student learning within the classroom. These constructs provide the framework for analyzing student mental models in a population ecology unit with embedded evolution concepts. These constructs are interrogated further in the literature review of the next chapter.
Study Purpose

The purpose of this study was to explore student changes in conceptual development, beliefs, and motivations when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology. Most formal evolution instruction follows units on DNA and genetics and is taught later in the year in more traditional curricula. A recent survey of three college introductory textbooks by Nehm et al. (2010) found that the vast majority of evolutionary concepts and terms were isolated in specific evolution and diversity sections. These researchers proposed that this segregation may reinforce students' faulty reasoning and suggest that students' mental models of biology may reflect this conceptual mapping. Evolution and diversity may be conceptually framed as a peripheral concept, instead of central, unifying theme. Nehm, Kim, and Sheppard (2009) postulate that evolution should serve as conceptual organizer and facilitate student connections among facts and ideas by linking major core concepts and connecting knowledge domains.

Currently, there is no readily available literature to substantiate that student's conceptual development in evolution may be enhanced through the purposeful embedding of evolution within instructional units outside of formal evolution chapters. There are several influential recommendations from literature that have served as a catalyst for this curriculum and subsequent study. This approach is modeled after the curriculum suggestions in articles from *The American Biology Teacher* (Alles, 2001; Flammer, 2006; Hillis, 2007; Nickels, Nelson, & Beard, 1996). This literature encouraged curricular decisions that incorporate evolution early in the year by
introducing evolution-based through classification and evolution activities from the
Evolution and Nature of Science Institutes (ENSI) web site to help reduce students'
conflict, after first explicitly teaching the NOS concepts. Flammer (2006) credits his
ideas for this curriculum from the 1963 BSCS Blue Version text and posits making
evolution a central theme in biology instruction by placing evolution units more toward
the beginning of the school year. These ideas served as a catalyst for embedding
evolution in a unit on population ecology.

Research Questions

This researcher wanted to know how this pedagogical strategy influenced
students' conceptual understandings, beliefs, and motivations. The specific questions
addressed in this study are:

1. What are the observed changes in student's conceptual development,
   epistemology, and motivation when evolution concepts are embedded and
   explicit reflective discourse is used in a unit for population ecology?

2. In what ways does explicit reflection influence students' mental models within
   this population ecology unit?

Significance of this Study

Science education research over the past 30 years reveals that the teaching and
learning of evolution continues to be problematic. Variations, adaptations, and
competition are difficult concepts for students to learn because their everyday meanings
are often deeply engrained. A curriculum approach that purposefully confronts students'
alternative conceptions through explicit reflective discourse within contextual topics
affords multiple opportunities for cognitive dissonance, contemplation, and revision of ideas through deep engagement (Dole & Sinatra, 1998; Sinatra 2005). Inquiries and activities with evolution ideas embedded within instructional units outside formal evolution chapters scaffold experiences and give students chances to make topical connections.

Providing students with opportunities to engage constructs in evolution through inquiry and argumentation with explicit reflection on questions that probe for alternate conceptions should promote restructuring and revision of those conceptions. The relationship between ecology and evolution may seem to be disparate biological topics to students. Natural selection concepts, like competition and struggle for survival, can be included in discussions of exponential and logistic population growth and other concepts in population ecology. Student's mental restructuring may be helped by nesting or embedding evolution concepts within seemingly disparate topics and giving perspicuous attention to alternative conceptions through explicit reflective discourse.

The purposefully linking or making topical connections with evolution, students may develop more scientific, coherent frameworks or mental models, instead of accumulated pieces of knowledge or p-prims (diSessa, 1993; Hammer & Elby, 2002). Southerland, Abrams, Cummins, and Anzelmo (2001) suggest that biology teachers seek approaches to activate phenomenological primitives, p-prims, to help students see that their everyday explanations of biological changes fall short of providing actual mechanisms for biological change. In other words, providing students with frequent opportunities to examine and reflect on their own incomplete explanations may
encourage and provide the motivation or dissatisfaction to seek more scientific alternatives.

**Synopsis of Methodology**

Twelve students in two 10th grade, general biology classes participated in this quasi-experimental, mixed-methods study. Quantitative and qualitative data were gathered from six students in each class (2 high-2 medium-2 low). Pre- and posttest surveys measured conceptual understanding of concepts in natural selection, science beliefs, and science motivations. This survey data was used descriptively to complement qualitative data. Qualitative data included written explanations, pre- and post-argument reflections, and pre- and posttest concept maps, along with a six-week, post-study final, concept map. Qualitative data was analyzed to determine ontological, epistemological, and motivational status.

The independent variable in this study was the use of explicit reflective discourse in the experimental class. Both classes engaged in the same five intervention activities that included evolution concepts in classroom environments supporting the Cognitive Reconstruction of Knowledge Model (CRKM) for conceptual change (Dole & Sinatra, 1998; Sinatra, 2005). Reflective discourse in the experimental class received one to two extra questions designed to probe for alternative conceptions explicitly through group and whole-class discourse.

**Study Limitations**

This study has several limitations that constrain the generalizability and must be disclosed. Generalizability is limited by the design of the research. The researcher as an
'insider' is also the practitioner. This can be both beneficial and problematic. This study was designed to give the most 'real' assessment of student's conceptual development, science beliefs, and motivations as possible. The duality of roles allowed closeness to the participants and controlled consistency in lesson instruction throughout the duration of the study. Students were comfortable, relaxed. Classroom interactions were natural and unsolicited without a third party observer and interviews. Throughout most of this study, students were unaware of research and responses were authentic. The only reminder of research were the extra surveys on scientific beliefs and motivations that students had to complete at the beginning and end of the study, along with the repetitive final concept map six weeks-post study.

Precautions in methodology were taken to ensure a balance between practitioner and researcher role albeit, as an 'insider.' The participants and classes were chosen by convenience sampling. Both quantitative and qualitative assessments were used. All instructional materials were made in advance. Intervention handouts were available electronically on the district network and data were saved and removed quickly, so that data could not be shared. Two formative assessments in ecology were graded without analysis of explanations from tasks. Data was not analyzed until four weeks after the final concept map. However, there are two major limitations to this study which may restrict its applicability outside this study.

One limitation in this study is that all artifacts were written. As the participants' regular classroom teacher, interviewing students would be too artificial and obtrusive. In addition, it was essential not to identify or draw attention to participants within each
class. Instead, all students completed written explanations and answers to reflection questions. Student written reflections served as a tool for revealing beliefs and motivations. However, this does not record interactive discourse which probe into student's questionable responses for clarification or access deeper meaning. Written artifacts may not reveal more latent beliefs and motivations. Therefore, students may not have fully disclosed their beliefs and motivations.

The second constraining feature of this study is that all student responses are coded and interpreted through one, single lens. That lens is shared by both the practitioner and researcher. This limitation is balanced by using current literature based tasks on similar phenomena and scholarly interpretations. Analysis of student explanations and propositions may, in fact, have been more rigid than current scholarship in some respects, due to overcompensation of dual roles.

**Researcher Perspectives**

Teaching science has been a professionally rewarding and personally challenging career for this researcher. As a National Board Certification in Adolescence and Young Adult Science, it is intrinsically rewarding to be an active participant in the student learning process. It is personally challenging and rewarding to help develop students' scientific attitudes and inspire curiosity in science not only through a creative curriculum, but by aiming to meet the educational and psychological needs of all students inclusively. This also means respecting cultures and worldviews.

Learning science should include an understanding that science knowledge is empirically and tentatively constructed endeavor. Scientific literacy means being able to
value and appreciate the kinds of knowledge that comes from the scientific enterprise. From this perspective, learning is actively constructing understanding by engaging in social interactions that challenge and extend personal understanding. Designing lessons that foster and maximize social and individual learning is priority from this perspective.

Some of the problems associated with the teaching and learning of evolution may be reduced and/or replaced with more critical scientific reasoning through the creative and opportunistic embedding of evolutionary concepts, along with perspicuous attention to alternative conceptions. This curriculum is a learning progression evolution that explicitly embeds concepts and activities throughout the curriculum, without direct instruction in the theory of evolution until formal chapters later in the year.
Definitions of Key Terms

In this section, key terms are defined to assist the reader in this scholarship. This is particularly important considering the many definitions and uses of the terms surrounding the construct of epistemology.

Alternate conceptions - Alternate conceptions are conceptual understandings that vary from the scientifically accepted view (Hewson & Hewson, 1984). Used reciprocally with the term 'misconception', which is used in literature when cited in literature. 'Alternate conceptions' is preferred by researcher and used where appropriate.

Conceptual change - In this study, conceptual change is equivalent to learning, since students have existing constructed preconceptions. Conceptual change can be enrichment or revisions to existing conceptions or specific theories or radical conceptual change consists of ontological shifts in framework theories (Vosniadou, 1994; Vosniadou & Brewer, 1987, 1992).

Construct - A scientific concept or hypothesized psychological function.

Epistemic beliefs - In the science classroom, epistemic beliefs are students' beliefs about science through inquiry experiences and experiences. These beliefs are articulated through argumentation, written explanations, reflections and concept mapping proposition decisions. In this study, epistemic beliefs are equivalent to scientific epistemologies.

Explicit reflective discourse - Small group and whole class discussion focused on specific intervention questions. The goal of reflective discourse is to reveal students' alternative
conceptions. Discourse creates student awareness and dissatisfaction with current non-scientific conceptions and other motivations important for conceptual change.

**Inquiry** - In the constructivist classroom, this refers to a set of "activities of students in which they (children) develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world..." (NRC, 1996, p. 2). Inquiry is along a continuum from teacher centered with no inquiry, guided inquiry with teacher scaffolds, through open inquiry. In this research student participants will engage in guided inquiry with metacognitive scaffolds that require reflection.

**Mental model** - This construct will refer to student's ontological and epistemological conceptions as revealed in this study through concept mapping and in constructing explanations and arguments. This construct pertains to student's conceptual linking of the discipline core ideas and belief propositions as revealed through hybrid concept maps and artifacts. These models will illustrate the connectedness of the domain concepts. Mental models are revealed through argumentation reflection and explanation construction.

**Motivations in science** - Motivation is a category within the social/affective domain that is measured in this study. Motivations are important for self-regulation. Motivational components include; self-determination, self-efficacy, intrinsic motivation, and personal goals orientations like career and grade motivations and are measured by surveys. These components can be linked to components of the CRKM for conceptual change, which are included in analysis from a multidimensional perspective.

**Nature of science (NOS)** - The definition and philosophy of the nature of science best representative of this researchers and this document are described by Driver, Leach,
Millar, and Scott (1996). They refer to the nature of science as "...knowledge about science as opposed to scientific knowledge" (p. 3). The teaching and learning of science is not all about accumulating scientific concepts, but should include learning about the symbolic and socially negotiated nature of scientific knowledge (Driver, Leach, Millar, & Scott, 1996).

**Perspicuous attention**-The intentional practice of attending or addressing alternative conceptions with explicit examples and classroom discourse that deliberately and directly engages both cognitive and meta-cognitive conceptions. Cognitively, perspicuous reflection should create dissatisfaction with current alternative conceptions. Metacognitively students become aware of and attentive to their use of alternative conceptions in explanations, particularly explanations of causal need.

**P-prims**-Phenomenological primitives (p-prims) are fragmented, spontaneously constructed conceptions that students access to give explanation to scientific phenomena. Phenomenological primitives form an alternative theory of knowledge from a cognitive perspective. diSessa's (1993) theory of p-prims asserts that student's mental frameworks are not coherent but made of fragmented ideas. Because student conceptions do not form a coherent framework, students can use a variety of explanations for the same phenomena.

**Science argument**-The use of claims, evidence, and reasoning (Kenyon & Reiser, 2006; McNeill & Krajcik, 2006) used synonymously with scientific explanations in the classroom. Beginning the third week of the school year, students are explicitly given instruction in argumentation constructs with scaffold learning experiences, teacher
modeling, and community practice. Student argumentation becomes a normal epistemic practice as the class year unfolds.

**Scientific epistemology**-Scientific epistemology is a student's beliefs about the nature of science (NOS) constructs as assessed through quantitative survey and epistemic practices in this study. Students' scientific epistemologies are equivalent to Sandoval's (2005), 'practical epistemology'.
Chapter 2: Literature Review

The purpose of this study was to explore student changes in conceptual development, epistemology, and motivation when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology. Research focused on student's conceptual development in evolution, epistemological beliefs, and science motivations within a population ecology unit with embedded evolution concepts and activities. A multidimensional approach was used to analyze changes in evolutionary understanding, beliefs, and motivations within this ecology unit. (Duit & Treagust, 2003; Treagust & Duit, 2008; Venville & Treagust, 1998; Tyson, Venville, Harrison, & Treagust, 1997). This perspective considers the ontology, epistemology, and the social/affective dimensions involved when interpreting student’s conceptual change.

A multidimensional perspective framed this study and literature review. The first part of this literature review takes a broad look at the construction of science knowledge, beliefs, and motivations through the lens of constructivism. In the second part of the review, each perspective of the multidimensional framework is described and then probed as the relationships between these dimensions are examined within a conceptual change model. The final section of this review gives a general overview of the dimension constructs and data artifacts for each dimension within this study. A short literature summary follows.

Learning Science and Conceptual Change

Constructivism is a theory of learning and a belief orientation. A constructivist believes that current knowledge, beliefs, interest, and other motivational factors are used
to construct and interpret new knowledge through experiences with the external world. Science educators with this theoretical stance view student learning as an active process of constructing knowledge and forming beliefs about science. It has become a dominant pedagogical perspective in science education literature throughout the world. The idea of constructivism is that new knowledge is constructed from previous knowledge. Various positions or traditions have been explicated for over a century now originating with the works Piaget (1950/2010, 1975/1977) and Vygotsky (1934/1986; 1978).

Two broad traditions exist within constructivism that seem to occur heterogeneously (Matthews, 1994), but at the same time form a competing paradigm. These two orientations addressed in the first part of this literature review are social and cognitive constructivism. These theoretical views form the conceptual lens through which pedagogical methods and learning context is designed to uncover students’ preconceptions, revise conceptual frameworks, and promote epistemological, as well as dispositional development. The social notion of knowledge construction has its roots in Vygotskian learning theory, whereas, cognitive constructivism has its foundations grounded in the genetic epistemological stance of Piaget.

**Learning science from a socio-cultural perspective.**

The social construction of knowledge is learning, or 'meaning making', occurs through dialogue. At the heart of social constructivism is the belief that knowledge is constructed within a culture or situated within a context through the use of speech and language. Teachers use the Vygotskian concept of the *zone of proximal development* (Vygotsky, 1978). This zone is used to scaffold student experiences based on prior
knowledge and the constructing new knowledge with other students in the classroom through active, formal, social interactions. From a social perspective, determining a students' present conceptual understanding of a current topic is important. Vygotsky (1978) differentiated this type of more formal learning, different from more spontaneous, informal learning that occurs in the everyday interactions.

Science learning is centered on students' construction of new knowledge and understanding based on what they already know and believe through dialogue and classroom discourse (Driver, Leach, Millar, & Scott, 1996; Scott, Asoko, & Leach, 2007). Sfard (1998) refers to this way of science learning as participation, because learning is embedded in the context of talk and culture (p. 6). However, science learning as conceptual replacement or addition is not clearly defined as in the cognitive perspective (Scott, Asoko, & Leach, 2007). Science knowledge can be thought of as heterogeneous, in that students may retain common, everyday science knowledge, but also gain formal knowledge that can be accessed at different times (Scott, Asoko, & Leach, 2007).

**Learning science from a cognitive perspective.**

Much of the conceptual framework in current literature on students' understanding of science has underlying propositions from Piaget's (1950) assertions that cognitive schemata develop. Cognitive construction of knowledge involves an individual's organization of experiences and knowledge around schemata which is integrated or equilibrated into existing mental patterns or schemes of knowledge and experiences. An individual's 'knowledge making' involves acting on an object, processing or assimilating
the object by incorporating it as knowledge in a network of structures called schemata. If the concepts are new, then they are assimilated. Mental processes by which individuals equilibrate experiences into schemata are called accommodation (Piaget, 1950). Accommodation occurs when students' existing schema is restructured or rebuilt from existing frameworks or schemes to reach a sort of mental equilibrium or homeostasis.

From a cognitive perspective, most science learning comes about when knowledge schemes change through disequilibrium. Conceptual change involves the identification of students' pre-existing science conceptions and through organizing instruction so that student's knowledge is restructured or assimilated. Science learning from this perspective may be thought of as knowledge acquisition (Sfard, 1998). Sfard (1998) suggests that learning concepts is like acquiring them and then adding to them or revising them over time (p. 5).

There may not be consensus about whether knowledge is an individual construction first, then verbalized within a social group individually, or the reverse. Regardless, both perspectives agree on basic assumptions and epistemology regarding student learning in the classroom. Constructivist approaches require assessing students’ current beliefs and/or uncovering alternative conceptions. Both orientations acknowledge students active engagement and effort in the process of learning (Dole & Sinatra, 1998, Driver, Leach, Millar, & Scott, 1996; Pintrich, Marx, & Boyle, 1993). Conceptual change from a constructivist perspective, then must consider ontological, epistemological, and motivational dimensions of student learning. In the next section of
this literature review, the ontological dimensions that describe and influence conceptual change will be explained from a psychological and science education perspective.

**Conceptual Change from a Psychological Perspective**

Since Piaget (1950) asserted that schemata are built through assimilation and accommodation, much research has been completed about the specifics of his theory regarding the learning of biological concepts. Cognitive psychologists who study learning of science concepts place an emphasis on the developmental stage models or cognitive structures that provide insights and knowledge into the nature and processes involved in conceptual change. Developmental models and perspectives, like teleology (Keleman, 1999), knowledge restructuring (Vosniadou & Brewer, 1987), and ontological shifts (Ferrari & Chi, 1998) are built from Piagetian theory on global restructuring (Piaget, 1950,1975). Other psychologists base their perspectives on incomplete, cognitive frameworks or phenomenological primitives (diSessa, 1993; Southerland, Abrams, Cummins, & Anzelmo, 2001; Southerland, Demastes, & Peebles, 1996). These psychological orientations are discussed briefly, with a critique of positions in order to establish a conceptual framework for data analysis for this study.

**Developmental perspectives.**

Many alternative conceptions can be explained from a developmental psychology perspective (Sinatra, Brem, Evans, 2008). Teleology is a belief from Greek philosophers and is a perspective that things are made for a purpose (Mayr, 1988). From a biological perspective, explanations are teleological, if they give function, purpose, and goals to physiological processes, behaviors, and actions of species and individuals (Mayr, p. 38).
In developmental research, Kelemen (1999) found that children and adults both possess a teleological-functional construal of artifacts and biological properties, but they also differ in ways that present challenges.

Kelemen's (1999) research focused on describing the similarities and differences between adult and children's explanations and origins of the view designed for a purpose. In her studies, Kelemen looked for teleology in both biologic and physical explanations for artifacts. For example, when shown a picture of a pointed rock and asked whether it was pointed "so that animals would not sit on it and smash it (teleological) or because little bits of stuff piled up over a long period of time (physical)," children would endorse the teleological explanation (p. 464). Younger children could not differentiate between explanations that were biologic and those that were physical. Kelemen called this promiscuous teleology because all artifacts were viewed as designed for a purpose.

Keleman (1999, 2003) found that older children and adults tended to give explanations for phenomena selectively. Explanations were not teleological for the pointedness of rocks. Explanations for the long neck of a prehistoric reptile, *Cryptoclidus*, were teleological, because they could move more easily in water (Kelemen, 1999, 2003). These types of explanations assign purpose to the long neck.

Teleological reasoning is very closely related to the construct of intentionality, which assumes that events are purposeful and that they may be caused by an intentional agent (Evans, 2001). In addition to developmental limitations, students construct knowledge based on their experiences with the world and these constructions are not always scientific. Psychological or conceptual constructs can serve as explanations for
students' alternative conceptions and be barriers to conceptual change. Children very early can develop conceptions about science that are not accurate.

In Evans' (2001) study of school-age children and mothers from both religious, fundamentalist and non-fundamentalists schools, she found that students' natural history knowledge and religious beliefs were predictors of their evolutionary knowledge and religious creationistic orientations. She concluded students can develop evolutionary thought independent from the beliefs of their parents, but that customs and cultures can restrain the coherence of beliefs systems and cognitive frameworks.

**Framework theory.**

A similar explanation for knowledge structuring and conceptual change can be taken from *framework theory* (Vosniadou, 1994; Vosniadou & Brewer, 1992; Vosniadou, Vamvakoussi, & Skopelliti, 2008). According to this perspective, children begin to acquire and organize knowledge into narrow, intuitive, but coherent theories based on their everyday experiences. As students engage in formal science through instruction they form types of 'synthetic', but not scientific, models by modifying or enriching these conceptual frameworks (Vosniadou & Brewer, 1987). This enrichment involves the addition of conceptions and beliefs, known as presuppositions (Vosniadou, 1994, p. 46). The frames that make up these mental models are systems of ontological and epistemological commitments or presuppositions (Vosniadou, 1994; Vosniadou & Ioannides, 1998; Vosniadou, Vamvakoussi, & Skopelliti, 2008).

These models range from early formed naive theories to synthetic, hybrid-type models through more scientific models (Vosniadou, 2007; Vosniadou, Vamvakoussi, &
Skopelliti, 2008). For example, elementary students in Vosniadou and Brewer's (1992) study consistently held the alternative conceptions that the earth was a hollow sphere with people living on the flat surface. This presupposition is naive in that it categorizes the earth as a round, physical object and then as a flat disk. This mental model is drawn from observations on everyday experience. Students who are older have heterogeneous, synthetic models that combine both their intuitive and scientific knowledge obtained through formal learning. These synthetic models are non-scientific and can be deeply entrenched.

Revision of synthetic models can be a difficult and slow process (Vosniadou, 2007; Vosniadou & Brewer, 1992). "Furthermore, the process of conceptual change appears to involve a gradual lifting of the presuppositions of the framework theory allowing more sophisticated models...", (Vosniadou, Vamvakousi, & Skopelliti, 2008, p. 9). Revision can be at the level of *specific theory* or at the level of the *framework theory* (Vosniadou, 1994, p. 46). Revisions at the level of the framework theory involve changes in ontology (Vosniadou, 1994). These mental models need to be restructured radically or reorganized with the emergence of new framework (Vosniadou & Brewer, 1987, 1992).

**Framework theory and ontological changes.** An earlier study of conceptual change by Chi, Slotta, and deLeeuw's (1994) supported the ideas that revisions in ontology are difficult. These researchers referred to conceptual changes in ontology, ontological shifts. Chi and colleagues reasoned that conceptual change can be difficult for some student's because these conceptions are assigned to the wrong ontological category.
In this literature, Chi et al. (1994) discerned three ontological distinct categories: *matter* (*entities*) or things, *processes*, and *mental states* (p. 28). This idea is similar to framework theory revision, but is explicit and descriptive about the type of ontological change or shift needed to transform synthetic models to scientific propositional beliefs and framework theory (Chi, 2008; Vosniadou, Vamvakousi, & Skopelliti, 2008).

An example of an incorrect ontological classification used in the literature of Chi, Slotta, and deLeeuw's (1994) illustrates this point. The statement "A canary is an hour-long" and "A canary is blue" are both propositions, however, the first proposition is nonsensical and anomalous (p. 30). 'Hour-long' refers to time attribute, a wrong ontological category. Blue is a correct ontological attribute that could describe the canary, but may not be true. According to this idea, conceptual change involving ontological shifts reassigns a presupposed concept from one ontological category to another (p.27).

An example of conceptual change that illustrates revision of framework that involves ontological changes is found in the scholarship of Venville and Treagust (1998). In this research tenth grade students were studying the concept of genes within a genetics course. At the beginning of instruction 70% of the students in the study described genes as being passed down from parents to offspring, with only 42% characterizing them as having controlling capabilities (p. 1039). Genes were described as being more inert, particle-like and capable of being passed, much like an artifact through the family. At the end of instruction, only 44% associated genes with particles and 76% thought genes to be actively involved in controlling characteristics. This example represents a revision in
framework in the students' mental models due to ontological shifts from genes as artifacts or objects to genes as involved in a dynamic process.

**Coherent frameworks and conceptual change in evolution.**

Chi (2005, 2008) argued that natural selection is an emergent-process ontology. She reasons that student misconceptions arise because students conceptualize this process as a direct-process ontology (Chi, 2005, 2008). Characteristics of direct processes include: a) bounded or restrictedness, b) a clear beginning and end, c) participants or agents interact sequentially, d) dependent on other participants or agents, e) goal oriented, and f) can be caused by a single agent (Chi, 2008, p. 74-75). Examples of direct process include cell division and birds flying in a V-pattern (Chi). Characteristics of an emergent process include: a) continuous, b) unending, c) participants interact simultaneously, d) participants interact simultaneously, and e) can be caused by the collective interactions of all agents or participants (Chi, 2008, p. 74-75). These process characteristics, along with the characteristics of entities helped identify student's ontological category in this study.

Chi (2008) describes three types of conceptual change, based on three different "...grain sizes of conflicting knowledge." (p. 66). One type of change involves the addition or revision of individual beliefs, which can take place quickly, like reading refutational texts, studying diagrams, or other confrontational learning (Chi, 2008). The two other types of learning involve changes when conceptions are coherent. A second type of conceptual change is in mental model structuring. Chi (2008) refers to this as transformation (p. 67). Mental model transformation involves the revision of incorrect beliefs to scientific beliefs. These models can be an amalgamation of both inaccurate and
scientific beliefs. Chi (2008) refers to these as flawed mental models (p. 67). Flawed mental models can be transformed or revised into a correct, scientific models by "the accumulation of multiple belief revisions," (p. 70). Chi's flawed mental model seems similar to synthetic models (Vosniadou & Brewer, 1992). The third type of conceptual change involves changing ontological categories, or ontological shifts.

Ferrari and Chi's (1998) earlier study reported college students' explanations using natural selection concepts reflected more direct-process ontologies. Examples from this research are "mutations enabled the species to survive," rather than a more process-like response, "random mutations will occur that make one or more trees better adapted" (p. 1243). Emergent, process-oriented explanations for evolution are more difficult for students because they involve the lateral shifting of ontological categories. Chi refers to this type of conceptual change as ontological shifts. Student’s conceptions of evolution in terms of finite, bounded events, instead of a slow gradual, ongoing emergent process through geologic time requires students make ontological shifts (Ferrari & Chi, 1998).

There is a body of literature asserting that students fail to see their misconceptions as inadequate or errors in explanations for phenomena due to misalignment in ontological categories (Chi, 2005, 2008; Ferrari & Chi, 1998). Conceptual change involving beliefs revision within the same ontological category can be achieved more readily through instruction involving confrontation or conflict (dissatisfaction) with current beliefs (Chi, 2008). Flawed mental models must undergo transformation, either through multiple accumulations of beliefs revisions or through ontological shifts (Chi, 2008). Understanding natural selection requires developing a conceptual framework from
emergent-process ontology orientation, not as a direct process. Framework theory explains conceptual change in terms of the gradual disappearance or 'lifting' of initial, synthetic presuppositions of the framework theory which then allows for the development of more scientific mental models (Vosniadou, Vamvakousi, & Skopelliti, 2008).

**Phenomenological primitives (p-prims).**

diSessa (1993) departs from the perspective that student's conceptions form coherent frameworks. Instead he asserts that student understanding is best characterized as 'knowledge in pieces' or phenomenological primitives (p-prims). According to this description, core intuitions and experiential constructs can be accessed and utilized by students as they make sense of the contextual situation in which they are being used. di Sessa metaphorically linked the existence of p-prim conceptions to atoms within matter. These p-prims can be accessed and play a role in allowing students to explain and interpret novice experiences, though the students may not cognitively be aware of them.

**P-prims and conceptual change in evolution.**

Southland, Abrams, Cummins, and Anzelmo (2001) investigated student use of p-prims in biology. These researchers wanted to determine if students' explanations for biological concepts could be characterized through framework theory or p-prims. Students were shown four graphics depicting natural phenomena from a bean plant growing toward the sun, ptarmigan in summer and in winter, birds in V-formations, and a cactus with succulent leaves. Students were asked to give the proximate cause by explaining how the change occurs and give an ultimate causal explanation by elaborating why this change or phenomena occurs. Southerland et al. (2001) concluded that in each
of the four grades (2, 5, 8, 12) the majority of students responded with "...teleological reasoning pattern in which the ends of the situation are used as a causal agent in determining the means." (p. 341).

In this study these researchers found that many students' explanations for the biological phenomena showed a blending of explanation categories with teleology as (Southland, Abrams, Cummins, & Anzelmo, 2001). Categories included; 

*anthropomorphic, predetermined, proximate, ultimate, blended, teleological and don't know* (p. 332). Results were surprising since these researchers predicted differences in categories between grade levels, but found students' explanations shifted within categories within each grade without much difference between grades. There were extreme degrees of tentativeness in explanations for the four phenomena with all grades, except for the youngest. Southland and colleagues (2001) concluded that students have weak conceptual frameworks for explaining biological phenomena, and that spontaneous explanations are based more on p-prims. This may account for the tentativeness and shifting of explanations. These researchers identified *need* as a rationale for change as a possible biological p-prim (p. 344).

From a more pragmatic view, literature on learning evolutionary concepts supports both coherent, conceptual framework and p-prims (Bishop & Anderson, 1992; Brumby, 1984; Demastes, Good, & Peebles, 1996; Kampourakis & Zogza, 2008, 2009). diSessa (1993) did not rule out the existence of a conceptual framework when he developed his theory of phenomenalogical primitives.
Perhaps more psychological studies in the biological sciences may be needed to tease out and determine whether p-prims are situational, used in less formal contexts in conversations, or offered when students have not developed a coherent, scientific emergent-process ontology in evolutionary reasoning. Evans' (2008) investigations at natural history museums found that attendees shifted explanations from teleological to creationist to evolutionary depending on the organism. She suggested once again that perhaps this is due to causal flexibility as she has found in other studies. It has been suggested that attention to teleological explanation, as p-prims, may be used as an instructional tool to help students develop more accurate scientific explanations (Southerland, Abrams, Cummins, Anzelmo, 2001; Zohar & Ginossar, 1998).

In this study, Vosniadou's perspective of framework theory and the development of mental models (1994), along with Chi's (2005, 2008) ontological categories of direct and emergent process in natural selection make sense. This is the ontological and epistemological perspective that is used in research when interpreting conceptual change from a multidimensional perspective (Duit & Treagust, 2003; Treagust & Duit, 2008; Venville & Treagust, 1998).

**Conceptual Change from a Science Education Perspective**

Conceptual change models in literature over the past 20 years have underlying perspectives on accommodation and global restructuring from Piaget (1975,1977). These views, together with Kuhn's (1962) analysis of scientific discoveries in the history of science based on 'scientific revolutions' form the foundation for conceptual change models used in science education. Kuhn associated the restructuring of knowledge
through accommodation to historic paradigm shifts in scientific beliefs that caused radical changes that advance sciences and help to define NOS. Identifying this shift in perspectives helped mold modern conceptual change theories in science education.

One of the most prominent, traditional models of conceptual change that evolved from these influences was proposed by Posner, Strike, Hewson, and Gertzog in 1982. This model, known as the Conceptual Change Model (CCM) promoted the idea that certain cognitive conditions must be addressed to produce conceptual change in learners. First, the concept to be learned must be in conflict with or create learner dissatisfaction with their current conceptualizations (Posner, Strike, Hewson, & Gertzog, 1982). This new knowledge must be intelligible as well as plausible in order to be internalized coherently by the learner (Posner, Strike, Hewson, & Gertzog, 1982). The last condition for change is that there must be a sense of fruitfulness or usefulness with the new knowledge. Posner et al. considered these four epistemological constructs a student's conceptual ecology. Conceptual ecologies drive accommodation so that learning or conceptual change can take place.

The CCM guided much of the conceptual change research by providing guidelines for the implementation of instructional strategies in the 1980's. Posner, Strike, Hewson, and Gertzog (1982) recommend teaching strategies for the use of their CCM. Among their suggestions for student conceptual change include developing 'activities' that create cognitive conflicts (Hewson & Hewson, 1984).

Organizing instruction so that alternate conceptions are recognized and perspicuously addressed may help students form coherent scientific mental models.
Instructional strategies can include confronting students' conceptions with anomalous data and/or contradictory information that create dissatisfaction in students' current conceptions. Student activities and interventions should draw attention to or confronting alternate conceptions and then engage students in arguments and reflection that encourage assimilation or accommodation and revision.

**Alternative conceptions in evolution.**

Alternative conceptions in evolutionary theory are commonplace in both college and secondary students. Common, deeply entrenched, conceptions specific to natural selection that are relevant to this study include: (a) basic key concepts of use and disuse; (b) non-random differences in survival and reproduction; (c) variations and inheritance; (d) adaptations; and (e) changes in populations, and speciation (Anderson, Fisher, & Norman, 2002). There are some typical alternative, global presuppositions that are likely to be given as explanations for natural selection concepts, like need and purpose.

Researchers have found that the alternate, teleological conceptions are very common and found these explanations convincing for many students (Demastes, Good, & Peebles, 1996; Moore, Froehle, Kiernan, & Greenwald, 2006). Alternative, teleological concepts are widespread and embedded in many student explanations that have been heard in the classroom. For instance a student's explanation for the claws of the praying mantis might be that the 'praying mantis need claws to catch grasshoppers'. Another common alternative conception would for the claws of a praying mantis could be that, 'it needed to adapt to his environment and its claws made it possible for it to catch food'.
Additional research has emerged with a focus on understanding the conceptual change process using younger students with misconceptions, since students are holding on to their naive conceptions into adulthood. Demastes, Good, and Peebles (1996) concluded after their year-long study of high school students that conceptual changes for all students may not be mediated by one conceptual change event in a short period of time and recommend multiple engagements with these concepts.

**CCM and evolution education.**

The CCM has been used as a model in the study of evolution in the classroom and as a comparison for interpreting student understanding. Demastes, Good, and Peebles (1996) investigated learning evolution in high-school and discovered four patterns of conceptual change. Throughout the course of a year, these researchers conducted interviews, observations, and artifacts that uncovered four categories of conceptual change. Two types of student conceptual changes identified during the learning of evolution can occur more rapidly and model the CCM. Rapid changes can be more *cascading*, where one conceptual change, from evolution being more Lamarckian or changing from a need-based conceptual framework, had a domino effect on changing other concepts (Demastes, Good, & Peebles, 1996). Another sudden change can be *wholesale*, where changing one single conception about evolution, mutation, leads to accommodation or revision of student understanding of evolution (Demastes, Good, & Peebles, 1996).

These researchers found that learning complex concepts with interrelationships, like speciation and variation, do not occur quickly even with instruction that emphasizes
evolution throughout the curriculum. Demastes, Good, and Peebles' (1996) year-long research indicates that failure to accommodate changes in Lamarckian needs, lead only to incremental change. Another pattern of conceptual change included a kind of dualistic nature in that population changes were reasonable, but wider-scale macroevolution was rejected. Demastes' et al. (1996) research demonstrated that student patterns of understanding evolution differ and that accommodation or revision of synthetic models and alternative conceptions may not occur immediately within a lesson or unit for all students.

What can be gleaned from this study? There is individuality in learning, and conceptual change may not be packaged as a one-size-fits-all model. Demastes, Good, and Peebles' (1996) investigation into conceptual change in the learning of evolution in a year-long curriculum supports the idea that embedding evolution concepts throughout the curriculum may maximize opportunities for student conceptual change and development in understanding of evolution.

**Warming Trend and the CCM**

Some researchers found that the CCM model assumes that students have enough self-awareness and metacognition to examine their own ideas for deficiencies and evaluate alternative conceptions (Caravita & Halldén, 1994). Challenges have come from the view that this model presumes students are rational like scientists. Other findings suggest students may not recognize or realize conflict or may become dissatisfied with their present conceptions (Chinn & Malhotra, 2002; Vosniadou, 1994).
This model was also criticized because it does not account for students' with multiple conceptions or differing cultures (Driver, Leach, Millar, & Scott, 1996). Still others found that the CCM model was cold, in that it did not account for epistemological beliefs, motivations, attitudes, or other dispositions (Limón, 2001; Pintrich, Marx, & Boyle, 1993).

**CCM within a multidimensional framework perspective.**

Student learning cannot be considered to be a purely cognitive, scientific act as advocated in the CCM, when viewing conceptual change from a multidimensional framework. The literature of Pintrich, Marx, and Boyle (1993) demanded immediate attention when they argued for consideration of motivational and epistemological dimensions in conceptual change. They maintained the CCM presumed students were more like scientists and approached learning science as a rational, goal-directed act. This literature called for considering motivational constructs and contextual factors in the classroom when designing instruction for conceptual change.

Pintrich, Marx, and Boyle's (1993) suggested educators consider students as individuals within a learning community. In their analysis of the literature, they charged that conceptual change cannot be facilitated without considering students' motivational beliefs, goals, personal interests, task value, epistemological, and control beliefs, as well as self-efficacy. Since this literature, conceptual change research has focused on investigating the roles of beliefs and motivations (Dole & Sinatra, 1998; Sinatra & Pintrich, 2003; Vosniadou & Ioannides, 1998).
Viewing conceptual change from an epistemological perspective within a multidimensional framework mandates investigating students’ internalization of the concept and examining the status of conceptions in the minds of the students (Duit & Treagust, 2003; Venville & Treagust, 1996; Tyson, Venville, Harrison, & Treagust, 1997). The following section of this literature review explains how student epistemologies can be developed and discusses domain-specific epistemology relevant to this study.

**Epistemological Beliefs**

There are multiple definitions for epistemology. Hofer and Pintrich (1997) defined epistemology as a branch of philosophy that studies the nature of knowledge and knowing (p. 117). Personal epistemology as defined by Hofer (2002), is "...how the individual develops conceptions of knowledge and knowing and utilizes them in developing understanding of the world" (p. 4). Personal epistemological beliefs impact student learning and conceptual change in the science classroom. Modern-day research on epistemology beliefs began with Perry in 1954 and focused on the development of intelligence.

**Linear, developmental models.**

Perry (1970) was the first to suggest that the processes students used to make meaning of their experiences was not due to personality, but was more developmental. He devised four developmental positions on a continuum: dualism, multiplicity, relativism, and commitment within relativism. Individuals with a dualistic position, view the world as certain, black or white, right or wrong. This view is very absolutist in
orientation. Polar to this position are individuals who are more relativistic or qualitative. According to Perry (1970) individuals make commitments based on values, relationships, and personal identity. Though his study had limitations, with all male sampling, what emerged from his initial longitudinal study was a multitude of investigations that have not only challenged both his developmental claims and catalyzed intense research, but his initial work served as a foundation for current investigations into both personal and domain-specific epistemology in education.

Following Perry's (1970) developmental model for intellectual development, King and Kitchener (King & Kitchener, 1994; 2004; Kitchener & King, 1981) conducted many years of extensive investigations into the skills used in critical thinking. Their studies included mixed-gender interviews with individuals from high school through adulthood. Their research assessed students' reflective judgment using ill-structured problems with interviews in order to gain insight into individual monitoring processes (Hofer, 2002). King and Kitchener's intensive investigations led to the development of their Reflective Judgment Model, [RJM] (1981), which recognizes seven stages of reflective thinking.

King and Kitchener's (2004) studies focused on how individuals perceive the nature of knowledge and the ways to justify knowledge. In the RJM, seven stages of epistemological development are grouped into three levels. The pre-reflective, where knowledge is assumed to be certain, quasi-reflective, uncertainly is a part of the knowing process, and reflective, where evidence and reason is used in support of judgments (King & Kitchener). At the quasi-reflective level, individuals recognize that knowledge is
constructed and evidence is important to knowing. However, individuals may not always link evidence to conclusions and beliefs are often used in support of arguments (p. 6-9).

Similar research was conducted by Kuhn (1991) when she proposed that thinking was argumentative reasoning. She posited that argument was central to thinking and "that education was failing in its most central mission- teach students to think" (p. 5). In her research she interviewed individuals in four age groups from their teens, 20's, 40's, and 60's and investigated how and why individuals reasoned and used knowledge beliefs in argumentation. She thought of participants as theorist who brought causal theories during the reasoning of ill-structured problems (p. 21-43). She examined how the 40 participants used evidence to support their beliefs and found that many could not make appraisals as to the strength of their arguments. She also found that many relied on pseudo evidence to support claims.

What is significant in Kuhn's (1991) research is that she linked individual skills in argumentation as a means to reveal personal epistemologies, through the consideration and use of evidence. Individuals who are absolutist are least likely to show argumentative skills and evaluatists have developed skills in argumentation and can generate alternative theories (Kuhn, 1991, p. 194-195). Kuhn seems to have simplified Perry's model and brought to light that skills of argumentation can be used to predict the level of epistemological development and understanding.

The models just reviewed used differing participants, research questions, and methodologies, these studies shared similar intellectual, developmental findings with similar models based on the framework that Perry (1970) proposed. These models shared
similar patterns of development along a linear continuum. Intellectual development proceeds from a more absolute, authoritarian individual view of the nature of knowledge to a more contextual, construction, ambiguous view of the nature of knowledge and knowing. However, these studies were conducted to explore more common or everyday reasoning as opposed to in classrooms and academic settings (Hofer & Pintrich, 1997; Schommer, 1990).

**Multi-dimensional epistemological model.**

Schommer (1990) diverged from the developmental, linear approach to epistemological beliefs and concluded that they are multidimensional. She explored the epistemological beliefs of college students in classrooms using mixed methods with an epistemological questionnaire she developed that contained 63 items (p. 499). Students responded to a passage with a written conclusion task and a short test in the second experiment (p. 501). Schommer conceptualized personal epistemology as being a set of more independent beliefs in five dimensions instead of just a progressive, linear, unidimensional phenomenon. These factors were *innate ability, simple knowledge, omniscient authority, quick learning,* and *certain knowledge.* Students who believed knowledge was certain tended to write answers that had absolute conclusions. In addition, Schommer found that students who "believed in quick, all-or-none learning" were more likely to "overestimate their understanding of the passage." (p. 503).

Schommer's (1990) research was important to education, because it linked epistemology to the process of learning. She concluded that personal epistemologies "...affect students' processing of information and monitoring of their comprehension", (p.
503). Her research directly linked student epistemology to classroom performance.

Schommer asserted that "epistemological beliefs appear to affect critical interpretation of knowledge," (p. 503) and suggested that "students benefit from activities that raise their consciousness about the underpinnings of knowledge and learning and how their own epistemological views influence their learning" (Schommer, 1990, p. 504). Her investigations opened the door for classroom research on student learning with attention on epistemology, particularly for students in primary and secondary school.

Schommer (1993) linked epistemological development in high school students to predictions of academic performance. Schommer related students' epistemological belief about knowledge to the way they study and to the consistency of those beliefs. As student's progress through high school, their beliefs about simple knowledge, certain knowledge, and quick learning is decreased. If students believe knowledge simple or certain, a list of facts, then they will engage in quick learning study strategies. She found males and females were no different with regard to certain and simple knowledge. Females showed less confidence in their abilities, which may be due to more accuracy in their comprehension monitoring (Schommer, 1993, p 410). In a subsequent study, Schommer and colleagues confirmed these results (Schommer, Calvert, Gariglietti, & Bajaj, 1997).

What can be gleaned from Schommer's and other similar studies in specific content areas (Qian & Alvermann, 1995; 2000) is that students' epistemologies affect learning and understanding, and these beliefs should guide instructional strategies.
Personal Epistemological Beliefs

Past studies, like Kuhn's (1991) and Schommer's (1990, 1993) suggested student's science practice and academic performance can be influenced by their beliefs in intelligence and learning, especially when they face challenging tasks, like argumentation. Students with less sophisticated beliefs may not meet the challenges of learning difficult and complex concepts. Since Schommer's (1990) research there have been a number of differing arguments about the dimensions that make up epistemological beliefs.

Hofer and Pintrich (1997) argue that there are four dimensions that make up epistemological beliefs. According to Hofer and Pintrich these dimensions are *certainty of knowledge* (stability), *simplicity of knowledge* (structure), *source of knowing* (authority), and *justification for knowing* (evaluation of knowledge claims). The literature relevant to this study follows similar arguments of Hofer and Pintrich (1997), but views these dimensions through a narrower lens specific to science, since it is important to consider student epistemologies that influence student conceptual change in science (Driver, Leach, Millar, & Scott, 1996; Driver, Squires, Rushworth, & Wood-Robinson, 1994). Both knowledge and beliefs are seen as coming from experience, but scientific knowledge is generally regarded as developing from school or formal experiences, whereas scientific beliefs develop from more everyday experiences (Southerland, Sinatra, & Matthews, 2001).
**Epistemological beliefs in science.**

Research suggests that pre-existing ontological and epistemological beliefs can either facilitate or interfere with the conceptual change process (Chi, 2005, 2008; Vosniadou and Brewer, 1992; Vosniadou, Vamvakousi, & Skopelliti, 2008). Driver, Leach, Millar, and Scott (1996) focused on three epistemologies that students have concerning the NOS and the work of scientists. They argued that students believe: (a) the purpose of scientific work is to provide descriptions of events or phenomena (Driver, Leach, Millar, & Scott, 1996, p. 46-49), (b) theories and evidence are not two separate entities, rather many are naive realists and believe theories emerge from data (p. 49-54), and (3) science is a process of gathering facts, not as social enterprise within a community (p. 54-57). Studies in the literature of Driver et al. showed students believe the purpose of science was to discover facts about the way nature works and to seek answers to questions by performing experiments. Students did not view science as developing explanations for phenomena that is socially negotiated.

There is a variety of literature that explores general epistemological beliefs in science classes. Most of the literature has explored students' discipline-specific scientific beliefs in the physical sciences (Hammer, 1994; Vosniadou, 1992, 1994) or from an epistemic perspective using student written arguments (Sandoval, 2003; Sandoval & Millwood, 2005). The research of Elder (2002) used a type of mixed methods to explore the scientific beliefs of fifth graders during a four unit study on electricity. Elder found students’ epistemological beliefs about science ranged from a mixture of naïve to mature understanding. She found that few students believed that science seeks to explain the
natural phenomena and students’ definition of science consisted of doing activities and completing projects (Elder, 2002).

Elder's (2002) investigation affirmed that students differentiate between 'school science' and 'real science' (Driver, Leach, Millar, & Scott, 1996). Students considered themselves passive learners, relying on books and teachers, whereas scientists are active learners, exploring ideas and exhibiting curiosity (Elder, 2002). Elder’s research served as a catalyst for the development of the instrument that was used in this study that was designed by Conley, Pintrich, Vekiri and Harrison (2004).

Student’s scientific epistemological beliefs were assessed using the quantitative instrument developed by research of Conley, Pintrich, Vekiri, and Harrison (2004). Their research investigated five schools of fifth grade students during a nine-week unit on chemical properties of substances. The content of the science instruction was identical, however not all classes engaged in argumentation and reflection. Students were measured with both a pre and post- test survey designed by these researchers and are discussed in the next chapter. Contextual factors were not measured, but these researchers found that at the end of the study students had developed more sophisticated thinking about source and certainty of knowledge. This may be due to the curriculum, because students engaged in 'hands-on' observations, data collection, and making comparisons had more epistemological awareness (Conley, Pintrich, Vekiri, & Harrison, 2004).

These findings support the stance that a constructivist classroom can help the development of more sophisticated epistemological stances. Since students did not spend
much time engaged in argument and reflection, they did not show significant improvement on the justification or developmental dimensions (Conley, Pintrich, Vekiri, & Harrison, 2004). The instrument validated through the research of Conley, et al. was used to document changes in scientific epistemological beliefs in several dimensions. This survey instrument monitored students’ beliefs developed in this study.

**Epistemological Beliefs and Conceptual Change in Evolution**

Research seems to indicate that with problematic issues, like evolution, prior belief constructs are distinct from the acquisition and assimilation of substantive core knowledge. Research suggests that when knowledge is limited and the subject content is perceived to be controversial, as opposed to noncontroversial, beliefs and dispositions toward changing one's thinking may play an important role in its acceptance (Sinatra, Southerland, McConaughy, & Demastes, 2003). Sinatra, Southerland, McConaughy, and Demastes suggest an obstacle to understanding evolution may be a students’ openness to change their beliefs. This research is also in alignment with the results of Lawson and Worsnop (1992) and supports assertion that learner dispositions to change may be an essential component to learning evolution.

These two studies strongly suggest that belief identification, the degree to which one holds onto beliefs, showed a strong relationship to knowledge of evolution. Students learn how to use evidence to support claims and provide a line of reasoning, by requiring students to engage in science arguments and explanations. This helps reinforce NOS skills and clarifies how scientific knowledge differs from theistic knowledge. This can lead to deeper understanding and acceptance of evolution as theory.
There is evidence to support that conceptual change is influenced by not only by epistemological beliefs and prior knowledge, but motivations, values, and other dispositional factors, as well as the social context (Buehl & Alexander, 2005; Limón, 2001). Conceptual change often involves considering intentions, interest, and motivations (Limón Luque, 2003; Sinatra & Pintrich, 2003). These factors are components of the social/affective perspective that should be considered when viewing conceptual change from a multidimensional framework (Duit & Treagust, 2003; Treagust & Duit, 2008; Venville & Treagust, 1998; Tyson, Venville, Harrison, & Treagust, 1997). The following section of this review describes the influence of social/affective domain on learning and conceptual change. This domain will then be narrowed to the specific components of motivations that influence conceptual change relevant to this study.

Motivations

Most literature from educational psychology prior to Pintrich, Marx, and Boyle (1993) focused on conceptual change using the CCM. Though the CCM does has elements of intelligibility, plausibility, and fruitfulness, affective factors, like motivations, were virtually unaddressed. Pintrich et al. (1993) argued that viewing learning as a solely as cognitive function was a 'cold' view and that motivational beliefs needed to be elaborated in this model. In addition, these researchers recognized that classroom context can play a role in student motivation. Sinatra and Pintrich (2003) suggested conceptual change depends not on cognitive conflict alone, but depends on metacognitive, motivational and other affective processes that should be brought to the learners’ attention and control (p. 2). The social-cognitive theory developed by Bandura (1977)
forms that foundation for the majority of the motivational theories associated with student learning in the classroom. Motivation will be described as a construct within the larger social/affective domain.

Motivation explains why students strive for particular goals and their intensity and perseverance toward reaching those goals, as well as the feelings and emotions that characterize this process (Koballa & Glynn, 2007). Koballa and Glynn define motivation as "an internal state that arouses, directs, and sustains students' behavior" (p. 85). A more scientific definition was given by Sinatra (2005) when reflecting on the life’s works of a fellow colleague, Pintrich. She defined motivation as “a complex, multidimensional construct that interacts in dynamic ways with cognitive constructs such as background knowledge and metacognition,” (Sinatra, 2005, p. 109). According to Eccles and Wigfield (2002), motivation in education can be categorized into four theory areas. These theories focus on expectancies for success, task value, integrations of both expectancy and values, and social-cognitive theories (p.109). There are many other motivational models that explain how and why students have certain motivations, from attribution theory (Weiner, 1994) to goal theories (Dweck, 2000). This study endorses Pintrich and Schunk’s (2002) perspective on motivation. These researchers observed that motivation is not stable, and students can be motivated in multiple ways, depending on the situation. Their research supports the assertion that student's thoughts and beliefs about their motivations mediate their engagement in classroom activities and achievement.
Motivation can describe the basic needs that an individual wants, but most research has focused broadly on the social-cognitive constructs describing those motivations related to self-regulating behaviors (Pintrich, 2003). Motivational constructs are narrowed in this study and focus on the components of self-determination, self-efficacy, intrinsic motivation, and career and grade motivations. These motivational components or variables are described with a focus from Pintrich’s literature (2003) in terms of “What do students want?” (p. 669) and “What motivates student in classrooms?” (p. 671).

**Self-determination.**

Students want and need motivations of self-determination to be successful learners in the classroom. Self-determination can best be described as the perceived ability of control one has over his/her own learning (Deci, Koestner, & Ryan, 2001 Deci & Ryan, 1985; Koballa & Glynn, 2007). According to Pintrich (2003), self-determination is a model that integrates both needs and social-cognitive constructs (p. 670). Self-determination is mediated by social-cognitive constructs, like control beliefs, regulation styles and perceived competence, and effects student’s behavior and learning outcomes (Deci & Ryan, 1985; Ryan & Deci, 2000). Self-determination comprises three need constructs; autonomy, competence and relatedness. To be self-determined, individuals must experience autonomy or freedom in terms of their behavior and view it as 'self-determined' in order to develop a sense of locus of causality or control (Deci & Ryan, 1985; Ryan & Deci, 2000). Autonomy is similar to self-efficacy in this respect.
Students are autonomous when they believe that the outcome of learning is under their control.

Two other need-related variables make up the self-determination model. Competence is the need to master and be knowledgeable and capable in interactions with the environment (Deci & Ryan, 1985; Ryan & Deci, 2000; Pintrich, 2003). Students need to feel effective in dealing with classroom tasks and goals. The third component is the need for social group reinforcement, that is, the need to interact with classmates and belong to a group. Cooperative grouping and accomplishing tasks within a group, meets the needs of the student to experience being attached to a group. Students with high degrees of self-determination feel that they have control of their learning experiences. They would also feel a high degree of capability of learning the tasks required in order to meet achievement goals. They feel that they belong and are a contributing member to their cooperative group and class.

**Self-efficacy.**

Self-efficacy in a science student is the confidence and belief that he/she has in their own learning (Glynn & Koballa, 2006). According to Pintrich (2003), "adaptive self-efficacy and competence perceptions motivate students," (p. 671). A student with a high self-efficacious level readily believes he/she has the ability to accomplish that task at hand and do well in the inquiry, lab activity or argument. Self-efficacy is a belief judgment about self-competence (Linnenbrink & Pintrich, 2003) to accomplish the lesson, develop a coherent explanation, or devise a scientific argument. Students who have higher levels of self-efficacy can visualize their successes. However, competence
beliefs and self-efficacy must be adaptive, that is, that it represents an accurate perception of one’s capabilities.

Efficacy plays a fundamental role in self-regulation of motivation and students’ perseverance in the face of difficult classroom tasks (Bandura, 1997). Unless students believe that they can meet the desired lesson goals by accomplishing the learning task, they have little incentive to act or persevere when the inquiry task is challenging. Bandura argued that students who experience success on a regular basis raise their efficacy appraisals, which can lead to objective and critical thinking when difficulties or failures arise.

Efficacy affects the types of activities, tasks, and social engagements which students choose to become involved. In a recent study, the self-efficacy beliefs of older, high-school students admitted to science-related fields in college were assessed over a 5-year transitional, longitudinal study (Larose, Ratelle, Guay, Senécal, & Harvey, 2006). Result showed increasing self-efficacy with increases in academic and vocational outcomes. The majority of participants possessed high levels of science self-efficacy with a decline in only about 30% of the participants. The results of this study supported Bandura’s (1997) ideas about student success on a regular basis raise their self-efficacy.

**Intrinsic motivation.**

Ryan and Deci (2000) define intrinsic motivation as “the inherent tendency to seek out novelty and challenges, to extend and exercise one’s capacities, to explore, and to learn” (p. 70). The self-determination theory can explain motivational and need differences between extrinsic and intrinsic continuums. Intrinsic motivation reflects
behavior and deep engagement undertaken because of enjoyment and interest. There is a high degree of perceived autonomy when students are intrinsically motivated. Whereas, extrinsic motivation reflects behavior and learning brought about by external pressures or value placed on the behavior. Deci and Ryan (2000) identified four types of extrinsic motivated styles from external to internal locus of control or self-determination to explain one’s ability to self-regulate or have self-determination within the context of extrinsic motivational factors.

According to Ryan and Deci (2000), there is a continuum in which internalization of extrinsic motivation can be related to learning and self-determination based on the types of extrinsic motivators and students’ perceived locus of control. At one end of the continuum there is no intrinsic motivation that would be attached to the behavior nor any self-determination associated with not valuing an activity. An example would be proceeding orderly during a high school fire drill and standing in single file (Ryan & Deci). At the center of the continuum would be a type of introjected regulation (Deci, Ryan, & Williams, 1996), where motivations are still external, but perceived locus of control develops internally and internal regulatory processes range from compliance with rewards and punishments to awareness and a synthesis of self (Ryan & Deci, 2000). At the opposite end a student would be self-determined and capable of regulation through identification or the conscious valuing of the behavioral goal or identified regulation.

Self-determined students have identity and sense of self to internalize the motivator and assimilate it as part of self, though the motivators could still be extrinsic (Deci & Ryan, 1985; Ryan and Deci, 2000). In this way, external motivation becomes
internalized, self-regulated, and self-determined. This suggests that pedagogy with autonomous extrinsic motivators and engagement would nurture the development of self-determination. Deci, Ryan, and Williams’ (1996) research in education have elucidated the negative effects extrinsic rewards have on intrinsic motivation by lowering feelings of competence and autonomy in students. Not only that, but threats, pressures, and other external negative external directives toward individuals lower their sense of security and relatedness. Appropriately constructed optimal challenges and activities, like constructive feedback and positive communications, promote intrinsic motivation through the development of competence, sense of personal efficacy, and self-determination.

**Career and grade motivations.**

Both career and grade motivational components comprise an area of research that involve theories that are focused on reasons for engagement. This scholarship involves goals and goal orientation theories. There are two main kinds of goal patterns that have evolved from research and these are identified as *performance* and *mastery* goals (Eccles & Wigfield, 2002; Pintrich, 2003). Student motivations that focus on performance goals concentrate on demonstrating ability, obtaining recognition of high ability, and trying to maximize favorable evaluations of their abilities, by comparing themselves relative to other students (Pintrich, 2003, p. 676).

Mastery goals are associated with motivations to learning for understanding and developing new skills with a focus on self-improvement (Pintrich, 2003, p. 676). Mastery goals have been associated with high levels of intrinsic motivation and other
higher motivations and behaviors. Mastery goals may be viewed more positively than performance goals. Generally speaking, students with high mastery goals in science would likely possess higher motivations in career and might be less likely to assign a high task value to achieving only an “A” on an assignment. However, a dichotomous characterization of performance and mastery may be too simplistic (Pintrich, 2003) and may, perhaps, be situational. Further elaboration about the relationship between the motivational variables follows.

**Motivations in the Science Classroom**

The components of motivation just described are mutually supporting. They are target assessment motivators that will be used in this study (Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011). Students with high levels of intrinsic motivation to learn science would be expected to orientate strongly towards other motivators, like careers in science. Conversely, students with low levels of self-determination, would be predicted to have low levels in other motivators, like intrinsic motivation. Sub-levels or attributes within motivational variables, like goals motivations and mastery goals, can be linked to seeking challenging tasks and generating effective strategies in the face of obstacles (Dweck & Leggett, 1988).

Students are not only motivated by the goals, tasks, and their social group. They are also motivated by the classroom context. In an early study on motivation and self-regulation motivations, Pintrich and De Groot (1990) investigated 15 classes of seventh and eighth grade students in their science classes using a 56-item instrument to discover the relationship between three motivational components and their effects on self-
regulation. Their research revealed that self-efficacy and intrinsic motivation were positively related to student cognitive engagement and performance.

In another similar study with seventh grade science students in differing classrooms, Pintrich, Roeser, and DeGroot (1994) compared motivations and self-regulating components. They found classroom and teacher differences are related to motivation and self-regulation differences in students. Students reported that they were more likely to focus on learning and mastery goals and have higher interests, when work was interesting, the teacher provided good explanations, and allowed them to work together (Pintrich, Roeser, & DeGroot, 1994). Students who were given task choices and freedoms showed higher intrinsic motivation, as well. These motivators relate to the autonomy development, competency, and relatedness components of self-determination. Higher intrinsic motivation can also be traced to self-efficacy development in students.

Motivation and conceptual change in evolution.

Students can reveal alternate conceptions that are teleological when constructing explanations for evolutionary change. Some student explanations demand much more than an enrichment in conceptions, but rather a revision in current framework theories (Vosniadou, 1994). In this study, the instructional context was designed to increase student motivations by providing students opportunities to engage in inquiries, build arguments with small groups and partners. The objective was to cultivate high interest and promote intentional conceptual change. Southerland and Sinatra (2003) suggested evolution instruction should focus on making student's aware of their alternative conceptions, beliefs, goals, and motivations. In order for students to become aware of the
need for conceptual change, lessons should focus on making students aware of their conceptions and motivations. This is the intent of explicit reflective discourse in this study. Students in small groups and whole class engage in discourse on focused intervention questions

Instructional efforts can bring dissatisfaction with current conceptions and willingness to change. This type of conceptual change requires considerable effort, and instructional contexts that require reflection and promotion of self-regulation may facilitate this change (Limón Luque, 2003, p. 138-139). Students must become aware of the need for change or competence and then become aware of what needs to change in their conceptions and beliefs. Limón and Carretero (1997) found if student interest in the tasks is high, then willingness to change is more likely even though their knowledge in the domain is low. Their case study with 11 grade students on the origins of life also revealed that high interest in the task, as well as high knowledge level in the domain brought about conceptual change only if the student saw the change as useful and relevant for their goals (Limón & Carretero, 1997).

The scholarship of Southerland and Sinatra (2003) argued that intentional conceptual change in learning biological evolution requires students develop epistemological beliefs and dispositions that moderate goals for learning, when the subject matter is considered controversial. It is their contention that instruction should focus on the development of scientific epistemologies, such as the tentativeness of scientific knowledge, and dispositions such as open-mindedness (Southerland & Sinatra, 2003). These intentional-level constructs will lead to the growth in more mastery-level
goals. As Linnenbrink and Pintrich (2003) have pointed out, mastery-level goals are influential in promoting conceptual change. Southerland and Sinatra support Scharmann's (1990) position that creating a diversified instructional strategy that targets both evolution concepts and the NOS constructs afford the most optimal conditions for intentional conceptual change. This strategy is the goal of an embedded curriculum with explicit reflection and perspicuous attention to alternative conceptions.

**Uniting Perspectives - Pedagogical Model**

The purpose of this study was to explore student changes in conceptual development, epistemology, and motivations when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology. A biology curriculum that nests and embeds evolution topics and activities may enhance evolutionary understanding and promote cohesive, scientific mental models. Two pedagogical strategies used in this study are: 1) Embed cognitively appropriate activities and concepts in a resourceful and creative way that nurtures student's ontological, epistemological, and affective development and 2) Promote intentional conceptual change by giving perspicuous attention to alternative conceptions.

There is support for these goals and a conceptual model that meets these conditions. Bell and Linn (2002) suggest that pedagogy should nurture knowledge integration, by providing opportunities for making connections and links among ideas. This “promotes a lifelong quest for pragmatic, coherent, and useful understanding of science” (p. 326). This is the purpose of embedding evolution throughout the curriculum. The model that best fits my conceptual framework and pedagogical design of this study
unit is the Cognitive Reconstruction of Knowledge Model (CRKM) devised and advocated by Dole and Sinatra (1998).

**CRKM and conceptual change.**

The CRKM was developed on the epistemological commitment that conceptual change is a complex process involving the learners’ background conceptions, beliefs, and motivations (Dole & Sinatra, 1998; Sinatra, 2005). This model considers student's prior existing conceptions and how instructional context promotes conceptual change. Learning or conceptual change occurs along an engagement continuum comparable to student's coherency, commitment, and motivations within the instructional context. If a student's existing mental model is synthetic and false, the student will not likely change conceptions easily. The CRKM views conceptual change along a continuum of engagement, and rarely as a one-time event, especially for deeply entrenched, alternative conceptions (Dole & Sinatra, 1998; Sinatra, 2005), which is different from the traditional CCM.

Dole and Sinatra (1998) recognized complex, multifarious, interactions between contextual conditions and learner characteristics could be optimized to create ideal conditions for conceptual change. Classroom contexts and lessons should be designed to encourage deep engagement and processing. The conceptual framework of this model suggest that cycles of learning that attending to the cognitive, epistemological, and motivational needs of students in the class room should promote conceptual change through progressive, intense engagement in lessons. The degree of engagement increases student likelihood of conceptual change. According to this model, students must perceive
the lessons or message, as intelligible or comprehensible, coherent, plausible, and rhetorically compelling (Dole & Sinatra, 1998; Sinatra, 2005). A learning context that meets these epistemological requirements would be more likely to promote change.

This CRKM emphasizes students' existing conceptions and beliefs as motivators that are key predictors to conceptual change. These motivating factors include dissatisfaction, as in the CCM, but Dole and Sinatra (1998) assert that student dissatisfaction with current conceptions is not the only motivator for conceptual change. In this study, student attributes of personal relevance, (akin to interest and self-efficacy), social context, (similar to the idea of need for relatedness), and need for cognition, (similar to intrinsic motivation) are catalysts for intentional conceptual change. These motivators set the CRKM apart from the CCM. Dole and Sinatra posited that the degree of engagement would mirror or be proportionate to the interaction of learner characteristics and the message (Dole & Sinatra, 1998, p. 121). Students with low cognition and motivations would have more superficial learning and with low metacognition, whereas high engagement is marked with deep processing and high levels of conceptual change.

A Model for Pedagogy

This model is most representative of the conceptual framework and pedagogical design used in this study. The CRKM best represents an ideal model for implementing conceptual change within this study unit. Data was readily coded, interpreted, analyzed from a multidimensional perspective through the use of this model because of its mirrored constructs. The multidimensional perspective guided analysis of conceptual
change in ontology, epistemology, and motivations resultant from this pedagogy. Figure 1 is this practitioner/researcher’s conceptions and theoretical framework for this study.

Student's ontological and epistemological frameworks.

This study explored students' conceptual development, epistemology, and motivations when components of natural selection were embedded within a population ecology unit. Perspicuous attention was given to alternative conceptions in the experimental group through reflective discourse. The instructional unit was designed to provide students with multiple learning opportunities to engage in natural selection concepts while concurrently learning core concepts in population ecology. Students were assessed both quantitatively with surveys and qualitatively through written work.

Students have not had formal introduction to the mechanism of natural selection. However, the components and inferences inherent in this principle were presented in this unit. Within this unit ecology concepts that were linked to natural selection were: a) limited resources and variation within populations, b) population growth and limiting factors, and c) differential survival (Mayr, 1988). Table 1 shows the content standards for this population ecology unit, as well as embedded evolution standards.
Table 1

*State Standards for Ecology and Evolution*

<table>
<thead>
<tr>
<th>State Ecology Standards</th>
<th>Embedded Evolution Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Relate how distribution and abundance of organisms and populations in ecosystems are limited by the ability of the ecosystem to recycle materials and the availability of matter, space, and energy.</td>
<td>- Explain that natural selection provides the following mechanism for evolution; undirected variation in inherited characteristics exist within every species. These characteristics may give individuals an advantage or disadvantage compared to others in surviving and reproducing. The advantaged offspring are more likely to survive and reproduce. Therefore, the proportion of individuals that have advantageous characteristics will increase. When an environment changes, the survival value of some inherited characteristics may change. - Explain that the variation of organisms within species increases the likelihood that at least some members of a species will survive under gradually changing environmental conditions.</td>
</tr>
<tr>
<td>- Explain how living things interact with biotic and abiotic components of the environment.</td>
<td></td>
</tr>
<tr>
<td>- Describe how matter cycles and energy flows through different levels of organization in living systems and between living systems and the physical environment.</td>
<td></td>
</tr>
<tr>
<td>- Conclude that ecosystems tend to have cyclic fluctuations around a state of approximate equilibrium that can change when climate changes, when one or more new species appear as a result of immigration or when one or more species disappear.</td>
<td></td>
</tr>
</tbody>
</table>

Student's understanding of evolution specific to populations and natural selection were gathered qualitatively for evidence of conceptual change with interpretation from a multidimensional perspective. Students created scientific explanations requiring proximate and ultimate causal connections. These explanations were coded for ontological and epistemological status whenever possible. Students constructed concept maps from propositions that helped determine student's ontological and epistemological restructuring or mental model revision over the study period (Shavelson, Ruiz-Primo, & Wiley, 2005; Vosniadou, 1994, Vosniadou & Ioannides, 1998). This study elicited student responses to pre- and post- argument reflections to help uncover student's ontological and epistemological status. This qualitative evidence will be explained further in the following sections.

**Explanations and reflections.**

Student explanations provided a rich body of data that can provide insight into student's ontological and epistemological frameworks. Students will be required to give explanations for biological phenomena with task scenarios from literature (Kampourakis & Zogza, 2008, 2009). These biological explanations required proximate and evolutionary causation and uncovered student's conceptual and belief status. Explanations showed student's alternative conceptions and beliefs, as well as status of strength, coherence, and commitment of these conceptions (Dole & Sinatra, 1998, Sinatra, 2005).

Written pre- and post-argument reflection responses revealed student ontological and epistemological presuppositions. These responses, together with explanations and
concept mapping disclosed the strength, coherency, and commitment of student conceptions by monitoring beliefs before and after argumentation.

**Concept mapping.**

Concept maps were used as both an instructional tool and as an assessment of students' conceptual frameworks or mental models. Concept maps are two-dimensional graphical representations that connect nodes or concepts with these propositions as well as mostly unidirectional, linking lines, called linking phrases in a hierarchical or other structure (Novak, 2002; Ruiz-Primo & Shavelson, 1996; Shavelson, Ruiz-Primo, & Wiley, 2005; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). These maps build on the associative model of cognitive mapping by adding propositions that link one concept to another (Novak; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). Propositions are declarative statements that link two or more concepts together to form a semantic unit (Novak 2002; Shavelson, Ruiz-Primo, & Wiley, 2005).

Concept maps are representations of students' mental models, because they show conceptual relationships by linking concepts together with declarative statements. These maps can be windows into their conceptual frameworks, because students constructed propositions (Shavelson, Ruiz-Primo, & Wiley, 2005). Since collections of propositions are considered specific theories or beliefs (Vosniadou, 1994; Vosniadou & Ioannides, 1998), concept maps can be considered a physical representation of student's mental model. Propositions or beliefs reveal not only a student's declarative knowledge, but procedural, schematic, and strategic knowledge ((Shavelson, Ruiz-Primo, & Wiley, 2005).
According to Shavelson, Ruiz-Primo, and Wiley (2005) knowledge is structured or layered. Procedural knowledge is knowledge demonstrated when you apply declarative knowledge to perform a procedure. Applying these researchers' descriptions of these knowledge types that illustrates is in molecular biology. In molecular biology, pipetting a certain volume of precipitated DNA requires that you know what the volume microliters represents and how to use the instrument. This is procedural knowledge. Knowing the physical phenomena behind DNA separation is schematic knowledge. Knowing when to use a certain proportional volume of template DNA, primers, and polymerase enzyme, why it must be that certain proportion, and how the process of polymerase chain reaction works is strategic knowledge.

Concept maps are thought to be representative of higher levels of knowledge, because knowing how to link concepts together involves procedure knowledge and why they should be linked is schematic knowledge (Shavelson, Ruiz-Primo, & Wiley, 2005). In this way, concept maps represent students' mental model structures.

**Science beliefs and motivational dimensions.**

Students' science beliefs and motivations are important constructs in the instructional context for intentional conceptual change (Sinatra & Pintrich, 2003). The four motivators within the CRKM framework for conceptual change are: 1) student dissatisfaction, 2) need for cognition or self-efficacy, 3) relevance that provides intrinsic motivation, and 4) social context that promotes relatedness (Dole & Sinatra, 1998; Sinatra, 2005). Dissatisfaction with the current status of the conception can be a motivator by creating cognitive conflict, because students perceive them as anomalies.
between their current conceptions and the new data (Chinn & Malhotra, 2002). In addition, dissatisfaction may create a need for competence.

In this study, intentional conceptual change through dissatisfaction was the goal of explicit reflective discourse in the experimental class. Dissatisfaction can be promoted by asking probing questions that require evolutionary responses. For example, students given collected samples of populations of common Carolina mantises can be asked to explain how this camouflaging and claws could come about from a shared ancestor of the cockroach. Teleological and synthetic explanations can be challenged within groups and in full class discussions. Students have opportunities to become aware of their current inaccurate, synthetic beliefs. This can stimulate and promote conceptual change.

As argued earlier, student dissatisfaction may not be the only motivator for conceptual change. Inquiry and argument tasks used in this study, along with the social context help nurture other aspects of student motivations. The challenging activities and argument building encourage autonomy because it allows for student choices and a degree of control over individual learning within a dyad. Self-efficacy can be fostered through the decision making and negotiation process needed for developing group arguments. Student successes with tasks required perseverance and patience in data analysis and variable manipulation. This helps support the development of self-determination and need for competence. Supporting argument decisions requires confidence and need for cognition. These tasks support increases in self-efficacy. Student pre-argument discussions within groups, goal setting, and planning serve to increase student motivations in career and grade motivations.
Reflections.

Written responses to post-argument questions can expose students' epistemic beliefs about their argument building and the nature of science knowledge. Probing questions can uncover students' beliefs regarding source, certainty, development, and justification of knowledge during argument building and argumentation. In this study, students were required to give evidence and justifications for their argument claims and give their thoughts on scientific knowledge building by defending their choices of evidence.

Student reflections were solicited immediately following the inquiry and argumentation tasks. These reflections were used to evaluate conceptual ecologies and motivations from both an epistemological and affective perspective. Reflection responses were aimed to reveal student motivations were interpreted, whenever possible, using the motivational constructs of the CRKM. Components of motivation used in the motivation survey instrument were also correlated to this conceptual change model. Responses were analyzed for motivations associated with dissatisfaction, personal relevance, need for cognition, and social context (Dole & Sinatra, 1998; Sinatra, 2005). In addition, responses were screened for epistemic beliefs and dispositions based on comprehensibility, coherency, plausibility, and rhetorically compelling, when possible (Dole & Sinatra, 1998; Sinatra, 2005).

Literature Summary

There are several key ideas presented in this literature review that serve as a conceptual framework for analysis of student work in this study. The primary goal of this
study was to explore changes in student's conceptions, since the objective of embedded evolution within topical domains of biology is to increase student evolutionary understanding. Attending to only one dimension, cognitive, has been argued to be an ineffective strategy for changing coherent, synthetic conceptions. Conceptual change should be viewed and analyzed from a multidimensional perspective incorporating the ontological, epistemological, and motivational dimensions of learning.

A key idea ascertained in the first part of this literature review on student learning or conceptual change is that students may have well-constructed, coherent explanations for natural selection, that are teleological and/or synthetic conceptions. Conceptual change can be a slow gradual process involving changes in ontological categories and presuppositions, when students display coherent, committed conceptions, because conceptual change involves mental model transformation. Student explanations requiring evolutionary causation can show direct-process ontology instead of scientific emergent-process ontology. Conceptual change should involve a sequence of activities and conceptual change events that challenge existing mental models with the intent to revise and restructure them with scientifically, accurate conceptions.

It has been argued that conceptual change is influenced by pre-existing ontological and epistemological presuppositions (Vosniadou & Brewer, 1992; Vosniadou, Vamvakousi, & Skopelliti, 2008). When student explanations are constructed by a need for change, then pedagogy should attempt address the inadequacy of this as a scientific, causal explanation for change. If students' explanations involve spontaneous use of p-prims, then pedagogy should attempt to activate these p-prims, revise students'
conceptions with the goal of creating a scientific, coherent framework of evolutionary conceptions (Southland, Abrams, Cummins, and Anzelmo, 2001). Perspicuous attention to these conceptions through explicit reflective discourse should promote students development of coherent, scientific mental models of evolution.

Schommer's (1990, 1993) research has shown that students' personal epistemological beliefs about absolute, certain, and authoritarian knowledge influences student's interpretations of knowledge and their own learning. Students can overrate their understanding, give absolute conclusions, and be less aware of their own learning. Specific science beliefs involving the dimensions of source, certainty, development and justification of knowledge can be developed through the argumentation process (Conley, Pintrich, Vekiri, & Harrison, 2004).

Literature supports the idea that conceptual change is influenced by motivations, that include the social context, task, interest, and intentions (Buehl & Alexander, 2005; Limón Luque, 2003: Sinatra & Pintrich, 2003). Sinatra and Pintrich (2003) argued that conceptual change does not solely pivot on creating dissatisfaction, but can depend on affective motivators that create interest and student control. Student can reveal alternate conceptions when they construct explanations that require evolutionary reasoning. These conceptions need revision not only in specific theories, but in ontological framework. Fostering high motivations through classroom social interactions, inquiries that require self-determination and autonomy, and argumentation supports the development of self-efficacy and need for cognition or intrinsic motivation should create the most optimal learning environment for conceptual change.
Chapter 3: Methods

The purpose of this study was to explore student changes in conceptual development, epistemology, and motivation when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology. One goal was to investigate changes in students' conceptions, beliefs, and science motivations when there was intentional, explicit reflective discourse that engages alternate conceptions within a population ecology unit with embedded evolution. Another goal was to determine student mental models during the study with an in-depth analysis of students' conceptions.

This study used a quasi-experimental research design involving two general, high-school biology classes. An ecology unit was chosen, because students had no previous formal instruction in evolution theory. Components of natural selection were embedded as part of an evolution learning progression. IRB approval for this study is included in Appendix A1.

This first portion of this chapter describes the research context and participants. This is followed by research design and details of data collection with methods of analysis. An in-depth description of key inquiries and intervention differences completes the majority of this chapter. The final section of this chapter addresses validity, reliability, trustworthiness, and limitations of this study in more detail.

Research Context

The school district where the study occurred could be considered typical, according to state performance assessments and performs 'excellent' on state report cards. Based on classroom observations, department meetings, discussions and collaborations
with other faculty, and personal experiences, it is generally agreed by science faculty that many students entering classrooms are not active learners. Many students believe science is a textbook of facts to be memorized, and science is practiced outside of school by 'real' scientists. Students often are not comfortable talking about science in small groups or in class discussions and are not accustomed to science discussions in class. Rather, they view science passively and come to class with expectations that teacher's impart knowledge to them. They often have very limited procedural knowledge about concepts like density, or measuring within the metric system. Students, if they have grown up in the district, are unfamiliar with concept maps and have limited lab investigative and inquiry experiences. Early pretests revealed that they have incomplete knowledge of the nature of science (NOS) and reveal many inaccurate, synthetic beliefs about science.

There seems to be a distinct, proactive movement to favor creationism over science in some of the churches around the school community. In formal and informal meetings and collegial discussions, science teachers often disclose that they encounter a wide variety of student responses, resistance, and naïve understanding of evolutionary theory in classes when reviewing basic NOS concepts even in physical science classes. At the beginning of any given year, one-third or more students in biology classes may be quick to disclose that they have already learned about evolution in church and it is a lie. A similar proportion of students are silent, seemingly undecided, and possibly unconvinced or withdrawn. Students can reveal their clear, sometimes hostile, denial of evolution as being a valid theory, and blur the boundaries between science knowledge and religious beliefs and lack of the NOS knowledge.
It is not uncommon to discover student reactions and tensions at the mention of the word 'evolution' can range from thick and vocal with overt combative stances, to subtle, more passive-aggressive behaviors, like closed arms, pursed lips, or rolling eyes with glances of approval about the room. Sometimes student anxiety, tensions, and angst may be so intense it sits heavy in the classroom, like a blanket of thick fog. Evolution can be perceived as a contentious and controversial issue in biology classes at the beginning of the year, even though it is the linchpin for understanding biology.

Participants

Student participants in this study live in a small urban, high-poverty, low income mid-western community (Ohio Department of Education [ODE], 2011). The district has a non-Caucasian ethnic diversity of 11%. The high school has 488 students at the end of the first semester of the 2011-2012 school year. Students in grades 9 through 12 have opportunities to earn weighted grades based on the classes chosen. Grade point averages (GPA) vary with 47 (10%) students earning GPA's between 4.00 and 4.70. There are 118 (24%) students with GPA's ranging from 3.50 to 3.99 or higher, and 219 (45%) have GPA's of 3.00 to 3.49 or higher.

All participants in this study were sophomores between 15-16 years old, although both classes had several repeating juniors. Average school class size was approximately 20-24 students with 9 traditional periods each day at 43 minutes (except Wednesday). Total time spent in class each week was approximately 200 minutes. The experimental group was chosen randomly by coin toss between the two regular biology classes
assigned to the researcher. All participant names were pseudo names. District and school participation and consent form is found in Appendix A2.

There are demographic variations between the two classes. The experimental group (ECO+E) had 18 students with 8 (44%) female and 10 males (56%) with 6 (33%) student families considered high poverty or low socioeconomic status (SES) and 5 (28%) students received special education services. The overall GPA average for the ECO+E class was 2.77. The non-equivalent, comparison group (ECO) had 14 students in the class with 5 (36%) female and 9 (64%) male with 1 (7%) student considered low SES and 2 students (14%) received special services. The overall GPA student average for the control group was 3.28. The ECO+E class was taught 8th period with the ECO class following immediately 9th period.

Nineteen students in both classes turned in signed parental and participant consent forms. The ECO+E class had 12 students. Six students (2 high-2medium-2 low) were selected as a subset for qualitative analysis and quantitative description based on overall GPA and final science grade earned the previous school year. In this subset, three students (50%) were low SES status with GPA's ranging from 1.92 through 4.02. One participant in the ECO+E class received special services and normal assessments are in small group settings, but this student participated without accommodations, during this study. Seven students in the control ECO class had signed parental and participant consents, and six students (2 high-2medium-2 low) were selected as the control subset. GPA's ranged from 3.11 through 4.23 in this study subset. All participants and their parents or guardians signed participation consent forms (see Appendices A3 and A4).
Mixed Methodological Approach

Mixed-methods research design allows researchers to gather and analyze both qualitative and quantitative data within the same scientific investigation. This methodology was a choice which provided "the most informative, complete, balanced, and useful research results" (Johnson, Onwuegbuzie, & Turner, 2007, p. 129). Mixed methodology is considered pragmatic philosophically, since it combines the deductive, more close-ended, quantitative approach with the more inductive, open-ended, qualitative approach (Creswell & Plano Clark, 2007). Johnson and Onwuegbuzie (2004), assert that mixed methods research sits in the middle of the dichotomy between quantitative and qualitative paradigms, and refer to this research design as the "new third chair" (p. 15). A mixed-methods approach was ideal for this study, because it had the potential to be more comprehensive, insightful, and synergistic, than either method alone.

Qualitative collections of student-produced electronic artifacts provided rich, expressive data that supported descriptive quantitative data gathered from surveys. Student artifacts included explanations, reflections, and concept maps. The method design enabled both types of data to be obtained in the most unobtrusive and least pervasive manner which helped negate perceptions of participation in a study (Hawthorne effect).

Embedded Design

This mixed-methods study had an embedded design feature. This design followed a one-phase, embedded experimental model (Creswell & Plano Clark, 2007, p. 69) where qualitative data was collected during the intervention period between quantitative pre-
and post-measures. This mixed-methods design was ideal for interpreting both quantitative and qualitative data from a multidimensional perspective. Multiple forms of data served as checks to support assertions and results from other sources of data. For example, student's survey results were compared to student's written artifacts to check for similar or conflicting conceptions that were not tangible or obvious in just one form of data.

Students' written explanations were used as an assessment of conceptual understanding and were analyzed consistent with current research on students' coherent explanations in natural selection used by Kampourakis & Zogza (2008, 2009). Additionally, these explanations were interpreted from an ontological and epistemological perspective. Pre- and post-argument reflection responses were coded and analyzed to determine student's ontological and epistemological status, as well as conceptual strength, coherency, and commitment as described in the Cognitive Reconstruction of Knowledge Model (Dole & Sinatra, [CRKM], 1998). Concept maps were made prior to intervention, immediately before intervention, and again at 6 weeks-post intervention. These maps were interpreted independently and combined together with other ontological and epistemological data to better interpret and understand students' mental models during this study. A diagram of the embedded design and sequence is shown in Figure 2.
Quasi-experimental Design

Quasi-experimental design with non-random assignment was employed in this investigation. Both the experimental and comparison groups were considered non-random, since the students were placed in classes prior to the start of the school year. Vogt (2007) considers quasi-experiments to be the "second-best alternative" to field experiments and have "some resemblance of a true experiment"(p. 108). Both the experimental class (ECO +E) and the control class (ECO) were taught in the afternoon with identical instruction by the researcher. There was a deliberate attempt to keep instruction in both classes as identical as possible. Students completed the same activities.
and were given equivalent time. The exception was the intervention questions that served as a focus for explicit reflective discourse. Reflective discourse was the independent variable or intervention within the ECO+E class. Table 2 shows the instructional unit progression along four weeks with key activities for explicit reflective discourse.

Table 2

Summary of Instructional Unit

<table>
<thead>
<tr>
<th>Week 1</th>
<th>*Insect Variations-Student Mantis Collections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Populations/Patterns of Distribution</td>
</tr>
<tr>
<td></td>
<td>Population Growth/ Distribution Patterns</td>
</tr>
<tr>
<td></td>
<td>Limiting factors- biotic/abiotic factors</td>
</tr>
<tr>
<td></td>
<td>*Populations and Competition -Computer Simulation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week 2</th>
<th>Limiting Factors/Carrying Capacity/Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*Argumentation Reflections</td>
</tr>
<tr>
<td></td>
<td>The Galápagos Finches</td>
</tr>
<tr>
<td></td>
<td>The Galápagos Finches</td>
</tr>
<tr>
<td></td>
<td>The Galápagos Finches</td>
</tr>
<tr>
<td></td>
<td>*Argumentation Reflections</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week 3</th>
<th>Formative Assessment I (Tasks 1,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Populations</td>
</tr>
<tr>
<td></td>
<td>*Peppered Moth Activity</td>
</tr>
<tr>
<td></td>
<td>Population Dynamics</td>
</tr>
<tr>
<td></td>
<td>Bug Hunt Camouflage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week 4</th>
<th>Bug Hunt Camouflage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*Argumentation Reflections</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week 5</th>
<th>Formative Assessment II (Tasks 3,4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summary and Assessments</td>
</tr>
</tbody>
</table>

Note: Key activities with reflective discourse are denoted with *.

The following section gives details about data collection and analysis. There were two research questions. Research Question 1 demanded data collection, analysis, and interpretation from a multidimensional perspective. Research Question 2 required an in-
depth focus on students' conceptual frameworks and connections students made between concepts. In this study, student mental models were described from an amalgamation of concept map data with ontological, epistemological, and motivational data to form a more cohesive, complete representation of conceptual and motivational changes resultant from this study.

Research Question 1

What are the observed changes in student's conceptual development, epistemology, and motivation when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology?

Research Question 2

In what ways does explicit reflection influence students' mental models within this population ecology unit?

**Quantitative Assessments**

Data gathered from survey instruments were used descriptively to characterize students’ cognitions, beliefs, and perceptions before and after completion of the ecology unit. Science epistemological beliefs were measured using the survey, Scientific Epistemological Beliefs (SEB), developed by Conley, Pintrich, Vekiri and Harrison (2004). Student motivations were considered using Glynn, Brickman, Armstrong, and Taasoobshirazi's (2011) revised instrument, Science Motivation Questionnaire II (SMQII). Evolutionary concepts were evaluated with the Conceptual Inventory of Natural Selection (CINS) developed by Anderson, Fisher, and Norman (2002).
Quantitative data from surveys provided numerical descriptions of student conceptual development in evolution during the intervention unit, along with latent variables of epistemological beliefs and motivations. Students completed the SEB and SMQII in one class period as unit pre- and posttests. The following day as part of normal unit pre- and posttest, students completed the CINS survey. This survey was embedded within a pretest with additional multiple choice and short answer responses covering topical concepts in population ecology. A detailed discussion of each instrument follows.

**Scientific epistemological beliefs.**

The SEB instrument was used to assess epistemological beliefs that students hold about selected assumptions and characteristics of the nature of science. The instrument was originally designed for younger, elementary students (Conley, Pintrich, Vekiri, & Harrison, 2004) but has been shown to be reliable for college students (Liang, Lee, & Tsai, 2010; Liang & Tsai, 2010). This 26-item, Likert scale, self-report tool measures along four multi-dimensional epistemological frameworks. This domain specific instrument was chosen because its dimensions correspond to Hofer and Pintrich's (1997) general epistemological dimensions. This instrument measured students' epistemological development over the course of intervention. Each dimension and an example is given below in Table 3.
Table 3

*Measured Epistemological Dimensions*

<table>
<thead>
<tr>
<th>Source</th>
<th>is concerned about the source of knowledge (5 items). Example: Everybody has to believe what scientists say.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certainty</td>
<td>refers to a belief in a right answer for science (6 items). Example: All questions in science have one right answer.</td>
</tr>
<tr>
<td>Development</td>
<td>measures beliefs about science as an evolving ever-changing subject (6 items). Example: Ideas in science sometimes change.</td>
</tr>
<tr>
<td>Justification</td>
<td>is concerned with the role of experimentation and the justification of knowledge in science (9 items). Example: In science, there can be more than one way for scientists to test their ideas.</td>
</tr>
</tbody>
</table>


Items were rated with scores of 1 (*strongly disagree*) and 5 (*strongly agree*) and all items are focused specifically on science. Low scores indicate more sophisticated and mature beliefs while high scores are indicative of less mature beliefs. Internal consistency or reliability for this instrument reported by Conley et al. (2004) are *Source*, 0.78, *Certainty*, 0.78, *Development*, 0.57, and *Justification*, 0.65. According to Vogt (2007) Cronbach's alpha range minimum is 0.70 or higher (p. 90). Alpha scores indicate this instrument is reliable (see Appendix B1 for instrument and personal communication).

**Science motivation questionnaire.**

Literature has documented the importance of motivational constructs in learning and achievement (Pintrich & DeGroot, 1990). The SMQII is a 25-item, multiple choice survey designed to measure students' motivation to learn science. This instrument measures five components of motivation on a 5 point Likert-type scale, (*Never to Always*)
This instrument measures students’ *intrinsic motivation, self-determination, self-efficacy, career motivation*, and *grade motivation*. These motivational components are important dimensions in self-regulation and have been linked extensively to student learning.

This SMQII is a revised version of the SMQ (Glynn & Koballa, 2006). It is five questions shorter and has a higher construct validity value. The reliability measures (Cronbach's alpha) for the subscales reported by Glynn and colleagues (2011) are: 0.89 for *intrinsic motivation*, 0.88 for *self-determination*, 0.83 for *self-efficacy*, 0.91 for *career motivation*, and 0.81 for *grade motivation*. These are excellent reliability scores, according to Vogt (2007). This instrument was used to monitor student level of engagement in each of the measured components within a constructivist, student-centered, classroom environment (see Appendix B2 for instrument and personal communication).

**Natural selection inventory.**

The justification for embedding and reflecting on evolution within unit lessons was to improve student understanding and coherency by making connections between seemingly disparate topics. One method for measurement was by using a reliable objective instrument. The CINS targets students’ conceptions in components of natural selection. The CINS instrument is a 20-question, multiple-choice test that uses common alternative conceptions in natural selection as distractors. This instrument was originally validated using non-science majors in general biology courses (Anderson, Fisher, &
Norman, 2002). This CINS was revised in 2004 and is usable in high school assessments (Anderson, personal communication, November 28, 2011). This CINS is criterion referenced. This means it can identify what specific concepts the students do not understand, because it is referenced against known scientific concepts (Vogt, 2007). This tool assessed student's understanding of the selected conceptual components of natural selection learned as a result of their engagement with these concepts within the population ecology unit (see Appendix B3 for instrument and communication).

The CINS instrument was ideal for measuring students' evolutionary understanding in this study for two reasons. First, according to the Anderson et al. (2002) this instrument addresses the five facts and three inferences described by Mayr (1988, p. 219). These concepts fit perfectly into a population ecology unit because typical population concepts of biotic potential, exponential growth, carrying capacity, limited resources and competition can be expanded to include concepts of variations, differential survival, and population changes over time. The reliability and validity of any measurement tool matters. The reliability refers to the consistency or replication ability this instrument. Though this survey was used on sophomores, the reliability score, (Kuder-Richardson 20), average for two sections of classes (n=206) is 0.61. This was considered acceptable to the author (Anderson, personal communication, November 28, 2011), but if this measurement of reliability is comparable with Cronbach's alpha, then according to Vogt (2007), it is slightly lower than the accepted 0.70 score. However, internal consistency of this instrument is supported by other studies (Nadolson & Sinatra, 2009; Nehm & Schonfeld, 2008).
Data Analysis

Since this was a quasi-experimental design, quantitative measures are descriptive of group and individual student scores from the surveys. Data are not meant to support making any statistical inferences. Instead, survey data was integrated with formative, ecology assessments and qualitative data. Explanations, responses to reflection questions, and concept maps were coded, categorized, or scored. This information was amalgamated together. This gave the most optimal and accurate description of students' conceptual changes and mental models.

Independent-samples t-tests were used to calculate the difference in mean scores for each variable and subsets within each variable, in order to determine differences between subset groups and individual students. For example, the four dimensions of epistemology were measured in the SEB. Both total scores and subset scores were transformed by computing mean scores. Descriptive statistics reported and used in this study were mean scores and differences in mean scores for each survey.

Qualitative Assessments

Written qualitative data were gathered from both the experimental and control classes during the instructional period. These artifacts included student explanations, pre- and post-argument reflection responses, and student-constructed concept maps. All three forms of data were coded and interpreted from an ontological, epistemological, and motivational perspective. The following portion of this chapter gives details about the qualitative methods. The first section describes data gathering methods used to determine student's evolutionary understanding from an ontological and epistemological
perspective. The second section provides a description of artifact scoring to determine students' science epistemological beliefs and motivations.

**Evolutionary understanding.**

Student's understanding of evolution was evaluated qualitatively by analyzing students' explanations, student pre- and post-argument reflection responses, and concept maps. Evolution concepts emphasized in this study unit were population dynamics, competition for resources, selective influences that include both environmental and interspecific competition, along with variations and adaptations, and differential survival. In this first section, student explanations to four tasks were examined for coherent, causality-based descriptions involving components of natural selection (Mayr, 1988, p. 219).

**Explanations.**

Student explanations to tasks were analyzed to determine whether they exhibited teleological conceptions, gave proximate, or evolutionary causation. In this study, explanations were assessed based on the interpretations by Ariew (2003) and Ferrari and Chi (1998) using the categorization and tasks from the literature of Kampourakis and Zogza (2008, 2009). Explanations were designated *teleological* when students gave intuitive or naive explanations using "intentional processes based on the fulfillment of predetermined end or a particular goal" (Kampourakis & Zogza, 2008, p. 30). Student explanations were considered *proximate*, when the biological trait was explained as a causal event at the individual level.
Proximate explanations described how the individuals within populations acquire their features and then explained the mechanism. In this study, this categorization would include all causal explanations that are attributed to events of the individual organism. *Proximate* included accurate scientific causes, like individual mutations. Explanations were also considered proximate, if they provided causation for variations of individuals within the populations, but explanations did not provide causation for population changes over time.

Student explanations were designated *evolutionary*, when they provided descriptions of population changes as an ongoing process over many generations. (Ferrari & Chi, 1998). Students had no previous formal instruction on the mechanistic propositions of natural selection. These tasks required students to draw on previous knowledge about molecular inheritance and sexual reproduction and make inferences about changes in populations over time.

Student written explanations were gathered twice during this study as part of the two formative assessments during the ecology unit. Two tasks were integrated into two electronic formative assessments which measured knowledge of population ecology concepts. Tasks 1 and 2 (Population Quiz 1) was taken electronically at the end of the second week. Tasks 3 and 4 (Population Quiz 2) was completed at the end of the fourth week (see Appendix B4). Tasks were not scored as part of the formative assessment and were not reviewed or discussed. Consequently, these tasks were not considered part of the planned intervention. Population Quiz scores reported reflect understanding of
ecological concepts presented in the instructional unit. The tasks given in Table 4 are directly from the scholarship of Kampourakis and Zogza (2009).

Table 4

<table>
<thead>
<tr>
<th>Explanation Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
</tr>
<tr>
<td>Task 2</td>
</tr>
<tr>
<td>Task 3</td>
</tr>
<tr>
<td>Task 4</td>
</tr>
</tbody>
</table>


Student explanations were reviewed for ontological and epistemological presuppositions. Student explanations were analyzed to determine ontology, as well as commitment and coherency of beliefs. This was necessary to interpret conceptual change
from a multidimensional perspective (Duit & Treagust, 2003; Treagust & Duit, 2008; Venville & Treagust, 1998). All four student explanations were examined for changes in mental model revision and progression from Tasks 1, 2 to Tasks 3, 4 that occurred two weeks later. Student explanations were used together with pre- and post-argument reflection responses and concept map propositions to support and enrich quantitative interpretations, as well as provide a reflective representation of students' mental models.

**Pre- and post-argument reflections.**

Student pre- and post-argument reflection responses followed two key activities, *The Galápagos Finches* (http://bguile.northwestern.edu/; Copyright 2009 by Northwestern University) and the modeling simulation, *Bug Hunt Camouflage* (Novak & Wilensky, 2005; Wilensky, 1999; Copyright 2005 by Uri Wilensky). Reflection questions were designed to reveal students' ontological and epistemological presuppositions after completion of the two activities and after class argumentation. Student responses to pre- and post-argument questions were coded and interpreted through an ontological and epistemological lens that integrates constructs from the framework theory (Vosniadou, 1994; Vosniadou & Brewer, 1992) and CRKM (Dole & Sinatra 1998). These constructs include ontological presuppositions, strength, coherence and commitment of conceptions, and beliefs about the task, like plausibility and comprehensibility (Dole & Sinatra, 2005; Vosniadou, 1994; Vosniadou & Brewer, 1992).

**Concept maps.**

Concept maps explored students' ontological and epistemological framework structures. Concept maps represent student's conceptual structuring of knowledge
(Shavelson, Ruiz-Primo, & Wiley, 2005). Results from student concept map propositions were used collectively with other data to describe student conceptual changes during the study. Concept maps form the physical and conceptual structural representation of students' mental models.

In this study, students constructed two types of concept maps. Students built pre- and 6-week final test concept maps by constructing propositions to form links to 12 concepts in a technique called C-mapping (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). The second type of concept map constructed was a 'hybrid' maps (H-map) that combined both a cognitive, associative map structure with propositions as in C technique. Students constructed H-maps as posttests at the end of the study. According to Shavelson, Ruiz-Primo, and Wiley (2005), H-maps may provide a glimpse or 'window' into the structure of students' declarative (conceptual) knowledge. Students were allotted two class periods for the post- and final tests. A total of approximately 60 minutes working time was given for these tasks with extra time taken to travel to the computer room, log into network, access the concept mapping site, and prepare for task. See Appendix B5 for concepts and student prompt.

Ruiz-Primo and Shavelson (1996) characterized concept maps as assessment tools based on tasks that demand evidence of student domain knowledge, distinct format for student responses, and a scoring system (p. 569). A brief discussion of how H-maps were created follows, along with the scoring technique for assessment. Both types of maps were constructed by the students using the proprietary concept mapping tool, Webspiration Classroom© (Inspiration Software, Inc.).
Hybrid maps.

Cognitive maps are structural, network-like representations of knowledge built using rated degrees of similarity between two concepts. These maps show structural networks between concepts after students have determined the degree of relatedness between the two concepts by assigning numerical values in a similarities survey (Inspiration Software, Inc.). According to the procedures laid out by Goldsmith, Johnson, and Acton (1991) cognitive-associative maps were created from proximity matrices made from student rankings of the relatedness between pairs of concepts. Student's proximity matrices were converted to weighted network-type structure. This conversion was accomplished by using algorithms in the software program Pfnets by Pathfinder (Schaneveldt, 1990). This network structure is a concept-association map that links concepts. An example of the similarity task is found in Table 5.

Table 5

<table>
<thead>
<tr>
<th>Concept Similarity Task</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Carrying capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Populations</td>
<td>1</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>7</td>
<td>Less related</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Med or DK</td>
<td></td>
<td></td>
<td>Med or DK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>More Related</td>
<td></td>
<td></td>
<td>More Related</td>
</tr>
<tr>
<td>2. Limiting factors</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>Individual organisms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Med or DK</td>
<td></td>
<td></td>
<td>More Related</td>
</tr>
</tbody>
</table>

Students reviewed concepts prior to judging relatedness and were asked to find a 'more related' and a 'less related' concept pair to get an 'anchor' or feel for what the task required (Goldsmith, Johnson, & Acton, 1991). Students were instructed to use the complete range of numbers 1-7 and if they were uncertain or did not know the
relationship to score near the middle of the number range as directed in the Goldsmith et al. (1991) study. Students made intuitive judgments between pairs with 12 domain concepts. These concepts were chosen from state ecology and evolution standards. This concept similarities ranking was given over two days to prevent fatigue. (see Appendix B6 a partial example from the first day).

Student cognitive-associative maps formed the network structure for the posttest H-map. A proximity matrix was constructed for each student and analyzed (Schaneveldt, 1990) with Pathfinder© software (Inspiration Software, Inc.). To construct a H-map, students first replicated their associative map or model. Then students created propositions that formed linkages between the concepts. Both conceptual modeling techniques are combined to give the best representation of students' mental models or 'windows into the mind' (Shavelson, Ruiz-Primo, & Wiley, 2005).

Concept maps can be scored in a variety of ways as an assessment tool (Ruiz-Primo & Shavelson, 1996). In this study, all three maps were assessed using accuracy of individual proposition quantitative scores (Ruiz-Primo & Shavelson; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). The number of propositions created for students' concept maps were not fixed. Student maps showed a variety of relationships, so individual proposition scores varied. Concept map accuracy score were determined by the sum of the individual propositional scores. Individual propositions were scored on a four-point scale: 0 for wrong or scientifically irrelevant propositions, 1 for partial, incorrect propositions, 2 for nearly correct, absolute, scientific propositions, and 3 for both
scientific correctness and scientific claims (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005).

Reliability and validity are important when using concept maps as assessment tools (Ruiz-Primo & Shavelson, 1996). The reliability of concept map scores refers to the consistency or generalizability of the assigned students' scores for their constructed, valid propositions (Ruiz-Primo & Shavelson, 1996). In typical studies conducted by Shavelson, Ruiz-Primo, and Wiley (2005), these researchers found very little variation in rater scores in concept map scoring methods that identify and evaluate propositions, regardless of mapping technique or concept sample (p. 420). In addition, studies have shown correlations between concept map scores and multiple choice scores have an historical validity range between 0.45-0.64, regardless of whether concepts were given or individually constructed (Shavelson, Ruiz-Primo, & Wiley, 2005).

**Structure.**

The structure of student concept maps was examined qualitatively for complexity. Yin, Vanides, Ruiz-Primo, Ayala, and Shavelson (2005) identified five structure types in the study of both created linking phrase (C) maps and selected linking phrase (S) maps. Concept maps with more linking and interconnected nodes with network-type structures are considered to represent expert, more complex knowledge (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). These five structure types identified from more simple to more complex structures are: 1) linear, 2) circular, 3) hubs/spokes, 4) tree, and 5) network/net (p. 170).
The following section describes how student post-argument reflection responses were used to assess students’ science epistemological beliefs and motivations.

**Science epistemological beliefs and motivations.**

Student post-argument responses to reflection questions assessed student's science beliefs and science motivations. Student responses to questions related to argument construction and use of evidence revealed student epistemic beliefs. These beliefs can be correlated to the dimensions assessed in the SEB survey and to the task message constructs in the CRKM. Eleven questions targeted the source, certainty, development, and justification dimensions (Conley, Pintrich, Vekiri, & Harrison, 2004). Student responses were coded and ranked as high or low in development according to the characteristics of the dimension (see p. 95). Students' beliefs about the task were identified, where possible. Responses to questions determined comprehensibility, coherency, plausibility, and rhetorically compelling characteristics of the task (Dole & Sinatra, 1998; Sinatra, 2005).

Reflection questions targeted motivational components that combined SMQII and CRKM constructs. Seven reflection questions targeted key motivational components of self-determination and autonomy, self-efficacy, intrinsic motivation and need for cognition, social context, and personal relevance and grade/career motivations (Dole & Sinatra, 1998; Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011; Sinatra, 2005). Responses were coded and interpreted has high or low in the development within each component. Results were amalgamated as self-motivations and career/grade
motivations for ease in interpretation and comparison (see Appendix B8 for reflection questions and construct analysis).

**Data amalgamation.**

Student data from surveys and formative assessments, task explanations, pre- and post-argument reflection responses, and concept maps measured student's conceptual development, beliefs, and motivations. In order to generate findings and answer the two research questions about the effects of explicit reflective discourse in this study, the four data sources were merged to provide an overall description of both quantitative and qualitative data.

Characterization of individual students and class comparisons regarding the conceptual development, coherency of beliefs, revision, and transformation of synthetic beliefs were supported by an amalgamation of data from multiple sources. Averages on (a) pre- and posttest CINS scores (b) two population ecology quizzes, (c) proposition accuracy, (d) proposition scores, and (e) proposition numbers were calculated so that generalized findings reflected conceptual development from multiple sources. Coded explanations to tasks, pre- and post-argument responses to focus and intervention questions, and scored propositions constructed in three concept map tests revealed students conceptual knowledge, helped determine conceptual coherency throughout the study, and exposed underpinned epistemological and ontological suppositions.

Student reflection responses were used to uncover students' science beliefs concerning argument development and knowledge construction in two key activities. Reflection responses measuring science beliefs development were scored (high or low)
based on the four measured dimensions on the SEB survey. SEB pre- and posttest survey scores on specific dimensions were compared with beliefs development scores in these same dimensions.

Science motivations revealed through written reflection responses were compared with SMQII results. Motivation components measured in reflection questions, relating to inquiry and argument building, were scored for motivational development (high or low) based on the five components in the SMQII survey. Scored motivational components were combined into two categories: self-motivations and career/grade motivations. Both combined components and individual motivation components were used to make overall conclusions about differences in class motivations.

Reflection responses were also used to generalize about the learning context and student engagement within the pedagogical model of this study. Students' beliefs about task message, motivations, and engagement levels were probed to help support or refute conclusions made about the effects of reflective discourse. The next portion of this chapter describes key instructional activities and intervention questions that were used to guide reflective discourse in the experimental (ECO+E) class. This unit in population ecology is part of a year-long evolution learning progression (see Appendix B7).

**Instructional Intervention**

Instructional intervention contained activities with embedded evolution concepts of natural selection within the unit on population ecology in this study. The control class (ECO) completed these same activities, but did not complete specific intervention questions designed to elicit alternative conceptions and make explicit, direct connections
to natural selection concepts. Interventions strategies included teacher probing and classroom discourse around selected intervention questions and discussions during argumentation. The following section describes the intervention specific to the ECO+E class.

**ECO+E**

Classroom and small group discussions in the ECO+E class periodically focused on prompted intervention questions designed to give perspicuous attention to alternate conceptions through reflective discourse. Students in this group received additional activity and pre- and post-argument reflective questions designed to expose their alternative conceptions in natural selection. These additional questions during and after activities provided opportunities to confront inaccurate, alternative conceptions and engage in discourse designed to create student dissatisfaction and cognitive dissonance necessary for intentional conceptual change. Other conceptual change motivator constructs inherent within the pedagogical design of the key intervention activities were held as consistently as possible in both classes. Table 6 shows the intervention questions with the names of each key activity.
Table 6

Intervention Questions for Reflective Discourse

Week 1
Activity 1: Mantis Population Class Activity-
- Fossil evidence and DNA analysis reveal that mantises and cockroaches shared a common ancestor about 30 million years ago. Explain how the forearm/claws of mantises could have come about.

Activity 2: Interspecific Competition, Lab simulation-
- Would all the individuals in the *P. aurelia* population be the same? Think about your answer and explain your reasoning.
- Suppose the environmental conditions in the test tube were changing and there was less oxygen available because stoppers had been placed on the tubes. How might this change your results? Use the terms: variations, limiting factors, resources, differential survival.

Week 2
Activity 3: The Galápagos Finches ©, Database Inquiry with argument building-
- How did some finches survive the catastrophe, while most finches did not?
- Why did some finches survive?

Week 3
Activity 4: Peppered Moth, Predation lab activity-
- How does variation in coloration affect the survival of an individual moth?
- How does variation in coloration relate to the moth's gene type?
- How do the genes in a population change over time? Explain how this happens?

Week 4
Activity 5: Bug Hunt Camouflage©, computer modeling activity-
- Why do some bugs develop camouflage?

Time spent on reflective discourse intervention in the ECO+E group varied consistently between 5 through 10 minutes for Activities 1, 2, and 4, since class time is short. Within the context of two argumentations (Activities 3 and 5), time spent on task intervention varied from approximately 10 through 15 minutes with student questioning and rebuttals. Whole-class reflective discussions were generally quicker than smaller group discussions. Total reflective time on intervention questions during the instruction unit was approximately 60 minutes (7.5%) in approximately 800 class minutes (40 min x
20 classes). Extra class time consumed by reflective discourse was used in the ECO class for summation of the day's concepts and key ideas, beginning homework, or anticipating the end of the school day with gathering and putting away equipment and supplies. Table 7 gives an overview of the five intervention activities and the week in which they were performed, along with the specific intervention questions used to stimulate reflective discourse.
<table>
<thead>
<tr>
<th>Activity</th>
<th>ECO</th>
<th>ECO+E</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mantis Population</td>
<td>Students make qualitative and quantitative observations of Carolina mantis population (student preserved samples) -Answer questions about mantises from observations and handout.</td>
<td>Students complete identical activity one intervention question for reflective discourse.</td>
</tr>
<tr>
<td>Lab simulation-Interspecific Competition</td>
<td>Students complete virtual lab using two protists- <em>P. caudatum</em> and <em>P. aurelia</em>. -Answer questions relating to population ecology</td>
<td>Students complete identical activity with two intervention questions for reflective discourse.</td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galápagos Finch</td>
<td><em>The Galápagos Finch</em> © Inquiry with argument building</td>
<td>Students complete identical activity with one additional focus and one post-argument question for reflection</td>
</tr>
<tr>
<td><strong>Week 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peppered Moth Predation</td>
<td>Students completed classic simulation of Kettlewell's industrial melanism using forceps To prey on mottled moths of three phenotypes. Students monitored changes in phenotypes.</td>
<td>Identical activity except phenotypes are associated with genes Intervention-monitor gene pool changes.</td>
</tr>
<tr>
<td><strong>Week 4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bug Hunt-computer modeling</td>
<td>Students completed NetLogos computer modeling inquiry <em>Bug Hunt Camouflage</em>© -Developed argument</td>
<td>Identical activity with one additional focus question and one post argument reflection question for discourse</td>
</tr>
</tbody>
</table>

Notes: The Galápagos Finches ([http://bguile.northwestern.edu/](http://bguile.northwestern.edu/); Copyright 2009 by Northwestern University); Bug Hunt Camouflage (Novak & Wilensky, 2005; Wilensky, 1999; Copyright 2005 by Uri Wilensky).

Class and group discourse prompted students to make explicit connections between components of natural selection with unit concepts of populations and individuals within an ecosystem. Students in the ECO+E class were encouraged to make causal explanations to describe how individuals acquire phenotypic variations and how changes in populations influence gene frequencies that can lead to new species. Students
were urged to connect these 'how' questions to 'why' individuals have differential survival and populations can change over time.

Intervention questions were intended to expose student's teleological thinking and synthetic conceptions. Students were challenged through reflective discourse to assess their conceptions, find inadequacies in, and revise their explanations through collaborative groups and in whole class discussions. The objective was to create student dissatisfaction with existing conceptions as an additional motivating stimulus for intentional conceptual change, while keeping all other motivation factors similar between groups.

**Key Intervention Activities**

Activities containing reflective discourse intervention in this study are considered key activities. These activities contain embedded evolution concepts and are generally reserved for formal evolution chapters. These key activities were used to illustrate both ecological and evolutionary principles. All student inquiries and activities were identical in both the ECO and ECO+E classes, with the exception of the intermittent reflective discourse around intervention questions. Activities, classroom context, and instructional strategies were designed following the Cognitive Reconstruction of Knowledge Model [CRKM], (Dole & Sinatra, 1998; Sinatra 2005) to maximize conceptual change. The 5-E learning cycle (Bybee et al., 2006; Bybee, 2010) approach was used where applicable. All key activity and intervention questions can be found in Appendix B9.

Specific lessons and activities included: a) guided inquiry on variations within mantis population, and peppered moth activities in weeks one and three, b) virtual lab
simulation on interspecific competition the end of the first week, c) data interpretation and model developing in *The Galápagos Finches*© ([http://bguile.northwestern.edu/](http://bguile.northwestern.edu/)) guided inquiry and argument in week two, and d) open-inquiry computer modeling activity, *Bug Hunt Camouflage*© (Novak & Wilensky, 2005; Wilensky, 1999) with argumentation during week four. Most activities involved dyad groupings. In class argumentation was completed by combining two dyads after *The Galápagos Finches*© and *Bug Hunt Camouflage*© activities. All activity questions for both classes, as well as intervention questions can be found in Appendix B7. More specific descriptions of the key intervention activities are discussed in the following section.

**Week 1.**

The mantis population activity was a guided inquiry completed in dyad groupings. This activity introduced students to the idea that there is variation within populations even though all individuals in that population seem to be all 'alike'. The mantis activity was designed to increase the motivational factors of personal relevance and interest. Actual mantises used in this activity were all collected and preserved by students earlier in the school year. Collections of common Carolina mantises were used to make both qualitative and quantitative observations about coloration, sizes, body proportions, and forearm/claw size. Students gathered group and class data and made of bar graphs of quantitative data. Questions were assigned for homework and discussed within small working groups, followed by full class reporting the next day. The intervention group, ECO+E were required to answer and discuss one additional intervention question.
The second key activity was a readily available, virtual lab on interspecific competition, from McGraw-Hill/Glencoe®, Population Biology, (http://www.mhhe.com/biosci/genbio/virtual_labs/BL_04/BL_04.html) and was completed at the end of the week. This virtual lab reinforced concepts of interspecific competition, limiting factors, logistic growth, and carrying capacity. Students were required to make estimates of paramecium populations, record data, construct graphs, and analyze data.

Motivational components of this lab activity included working in a dyad social context and in a virtual environment. It was hoped that these two elements would increase social cooperation and students would view this task as comprehensible and plausible, since the protists were easily counted and sampling estimation made easy with grids. These contextual characteristics were designed to influence conceptual change, according to the CRKM (Dole & Sinatra, 1998; Sinatra, 2005). All students completed task questions throughout the lab including building a hypothesis, estimating populations and gathering evidence, and applying ecological principles with completion of a few questions for homework. All questions were discussed the following day in class. Two intervention questions required students in the ECO+E class to give explanations using the concepts of variations, limited resources, and differential survival.

**Week 2.**

The third key activity completed was a guided inquiry using the finch database, *The Galápagos Finches®* (http://bguile.northwestern.edu/). This database was designed for middle and high school students (Sandoval, 2003; Sandoval & Millwood, 2005).
Students became familiar with features of the database the first day by exploring and looking for data to answer several specific questions. Then students were given the investigative focus question to develop an argument.

This database inquiry required students to make observations, organize, analyze data, and develop a model that explained their data. Student dyads provided evidence and justification for their group's claim on the complex problem of the finches on Daphne Major Island in the Galápagos. Students were required to formulate scientific arguments to support their interpretation of the data. Students in both groups constructed scientific explanations to explain population changes using concepts of biotic and abiotic factors limiting growth, population growth patterns, carrying capacity, and limited resources.

This context also provides opportunities for the ECO+E class to make justifications that include components of natural selection, like selective pressures, differential survival, beak adaptations, and selective fitness (Sandoval & Millwood, 2005) in order to answer their second investigative question. Intervention questions prompted students to give causal explanations to explain how the birds died and why other birds survived. All students responded to pre- and post-argument reflection questions after this key activity.

In addition to the conceptual challenges of this activity, exploration and argument building components were designed to increase students' self-motivations. Students had autonomy, because they could make choices, which can nurture self-efficacy and intrinsic motivation or need for cognition. Students' self-determination should also be considered, since most students have never had prior experience with a database. These are all
characteristic constructs inherent in the CRKM (Dole & Sinatra, 1998; Sinatra, 2005) that nurture engagement and intentional conceptual change.

**Week 3.**

In the fourth key activity, students engaged in a classical predator/prey relationship model that simulated Kettlewell's observations in peppered moths. This 'hands-on' activity was adapted from Lab-Aids© Natural Selection Experimentation Kit #91. Students used dark butterfly phenotypes (black, dark and light gray) on black/white and black/gray/white printed background. Students used forceps as beaks and survivors were doubled for each round. Students collected group and class data in three trials for each background. Students in both classes were required to record dyad and class data, construct graphs, and explain how the population changed in each generation or round.

In the ECO+E class, butterflies had associated 'gene types' with phenotypes (black= BB, dark gray= Bb, and light gray= bb). Students connected phenotypic changes with genotypic changes in the population over three generations. Within the class period, students were able to gather data. The following day, students constructed graphs and answered analysis and reflective questions in small groups. Students in the ECO+E class were prompted to make inferences that connect ecological factors with genetic variations, variations with predation and differential survival, and gene frequency changes in populations over time.

Student motivators in this activity included 'hands on' predation within a social context to nurture a high degree of engagement. Social context was fostered the
following day by cooperative completion of graphing, sharing, and social discourse. The social nature and personal physical manipulation inherent in this activity supported engagement. These are characteristic motivational constructs of the CRKM (Dole & Sinatra, 1998; Sinatra, 2005) and support student learning or conceptual change. This activity was designed to be a scaffold for the final key activity.

**Week 4.**

The final key activity, *Bug Hunt Camouflage*©, (Novak & Wilensky, 2005; Wilensky, 1999), students continued to explore predator/prey relationships by assuming the role of a predatory bird in a computer modeling simulation. This predatory bird must eat as many bugs as quickly as possible to stay alive. Students formulated their own questions and manipulate variables to answer to focus question. Students controlled variables of size of the bugs, carrying capacity, predation time, and mutation rate in differing environments. Students were required to give scientific arguments for their models. Students in both groups were prompted by an investigative focus question and were encouraged to watch and record trends in coloration (hue, saturation, brightness) over the predation period.

This activity had similar student motivators to the finch data base that support student engagement in the task. Students had autonomous control over variables, and the activity was completed in dyads to support a positive and engaging social context. The simulation was similar to many computer games and students were actively engaged in hunting the butterflies. The task message should be comprehensible and plausible. These are all important characteristics of the CRKM (Dole & Sinatra, 1998; Sinatra, 2005).
The final portion of this chapter describes concerns and precautions taken during design, execution, and analysis of data that are germane to this study due to the simultaneous role of both researcher and teacher. Aspects of experimental validity, ethics and confidentiality, and bias are described.

**Teacher as Researcher**

**Validity.**

Creswell and Plano (2007) define validity in the context of a mixed-methods study as "...the ability of the researcher to draw meaningful and accurate conclusions from all of the data in the study" (p. 146). The research design was chosen because of the nature of the dual role as both the teacher and researcher. Since this study was conducted as 'teacher as researcher', an uncommon position in doctoral educational research, it is important to acknowledge both roles for several reasons. The role of an *insider* (both teacher and researcher) creates closeness and the potential for dilemmas opposite of those experienced as an outside researcher coming into the classroom (Herr & Anderson, 2005).

Constant awareness and reflective journaling helped in the recognition and viewing of the classroom and data from an outsider perspective. Quantitative measures serve as descriptive data to be considered as additional support for inferences drawn from the evaluation of written qualitative data. According to Creswell and Plano (2007), validity of conclusions in mixed methodology can be strengthened by the unobtrusive gathering of data and using the same individuals and research questions when gathering and analyzing data (pp. 147-148). Every attempt was made to keep both classes as equal...
as possible, except for the brief amount of key intervention time in the ECO+E class. All qualitative data was written by the students as part of regular classroom activities. Because of the more nontraditional, pragmatic nature of the curriculum and small numbers of participants, external validity or generalizability of the inferences drawn from this study may not be transferrable to a larger population or other classroom contexts.

**Ethics and confidentiality.**

Communicating ethics of practice and confidentiality to parents and student participants before the study period helped minimize any feelings of coerciveness, partiality, and exploitation as a participant in this study. All pedagogical measures were taken to ensure that state science standards for the population ecology content were met in both the ECO+E and ECO classes, as the teacher and curriculum designer professionally and ethically responsible for student completion credit. As a researcher, all electronic copies of work were saved into students' own individual accounts. Data were accessed and saved in an external flash drive, locked in a file drawer, during the study. Student data was saved under numbers and pseudo names were assigned.

**Bias.**

As the teacher and researcher, every consideration was made to consistently inspect, code, and interpret qualitative data a minimum of three times. Explanation categorization and proposition scoring were consistently analyzed rigorously following strict rubric guidelines, which in some cases, may be more stringent than originally presented by researchers in the cited literature.
This teacher-researcher was reflective, evaluative, and pragmatic with approaches to solving problems of student engagement and learning within the pedagogical model presented in chapter two. However, acknowledgement and awareness that teaching experience over the years has given a perspective or bias based on these unique experiences and subjectivity. Not to acknowledge this perspective is to be non-reflexive.
Chapter 4: Results

The purpose of this study was to explore student changes in conceptual development, epistemology, and motivation when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology. This mixed-methods study has an embedded, quasi-experimental design. Student's conceptual development, as well as science epistemologies and motivations were measured with three pre- and post-test three surveys. Qualitative data were gathered, coded, and analyzed from a multidimensional perspective in two classes of tenth-grade (ECO and ECO+E), general biology students. Students constructed three pre-, post-, and final (6-Week) concept maps to help answer Research Question 2. The two research questions that served as a focus for this study are:

1. What are the observed changes in student's conceptual development, epistemology, and motivation when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology?

2. In what ways does explicit reflection influence students' mental models within this population ecology unit?

This chapter has four parts. The first three parts present results answering the first research question. Part 1 reports the results of the three pre and posttest surveys measuring student evolutionary understanding in natural selection, science epistemologies, and science motivations. Part 2 presents the results of four, written explanations assessing student's evolutionary development, as well as ontological and epistemological status. Part 3 shows the results from written reflections specific to
student's scientific epistemological beliefs and motivations. Part 4, the final part of this chapter, presents the results of three concept mapping tests (pre, post, and final) determining student mental models. These results answer the second research question and contribute to the conceptual analysis for research question one. Table 8 presents a summary of the research methodology.

Table 8

<table>
<thead>
<tr>
<th>Summary of Research Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Research Question</strong></td>
</tr>
<tr>
<td>1. What changes are observed in students' conceptual development, epistemology, and motivations when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology?</td>
</tr>
<tr>
<td>2. In what ways does explicit reflection influence students' mental models within this population ecology unit?</td>
</tr>
</tbody>
</table>

**Researcher Note**

A disclosure is necessary. During this study several students in the ECO class recognized and questioned the subtle differences in the questions on intervention activities. Since the school is relatively small, many the student participants are friends, engage in extra-curricular activities, and often study together. As a consequence, some results presented may have been influenced by the subsequent sharing of information and discussion between students in the ECO and ECO+E classes. To aide in results
interpretation and subsequent analysis, student data used in this study, and the research interpretative codes and notes are included in Appendix C1.

**Part 1: Survey Results**

Students completed three distinct surveys at two intervals (pre and posttest). These surveys measured student's evolutionary understanding, Conceptual Inventory of Natural Selection (CINS) science beliefs, Scientific Epistemological Beliefs (SEB) and science motivations, Science Motivation Questionnaire II (SMQII). The mean of values obtained from the pre- and posttest survey administrations are compared here and interpreted descriptively to characterize difference in the experience for the two groups of students.

**Summary of overall mean scores.**

Survey results for both the ECO and ECO+E classes show increases in student scores on the CINS. The mean score in the ECO class, on a scale of 0-20 for the CINS, was 7.67 on the pretest. Scores ranged from 6 to 10. The mean posttest score was 11.50, and scores ranged from 9 to 14. The difference between pre and posttest means was 3.83, showing that students increased by 3.38 points. The mean pretest score in the ECO+E class was a 6.67, and scores ranged from 5 to 10. The mean posttest score was 11.33 with scores ranging from 10 to 14. The mean difference between the pre and posttests scores was 4.67. Students in the ECO+E group scores increased by 4.67 points.

Student scores on the SEB and SMQII showed little change between pre- and posttest mean totals. Both surveys had a score range from 1-5. Overall students in the ECO+E class reported higher epistemological development ratings and science
motivations. The greatest difference between the classes in both surveys was a 0.77 gain from the SMQII in overall development of science motivation in the ECO+E class. The mean scores for each pre- and posttest were calculated and are seen in Table 9.

Table 9

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pretest Mean</th>
<th>Posttest Mean</th>
<th>Difference in Mean (Post-Pre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CINS</td>
<td>C(n=6) 7.67</td>
<td>11.50</td>
<td>3.83</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 6.67</td>
<td>11.33</td>
<td>4.67</td>
</tr>
<tr>
<td>SEB</td>
<td>C(n=6) 4.08</td>
<td>4.25</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 4.23</td>
<td>4.19</td>
<td>-0.37</td>
</tr>
<tr>
<td>SMQII</td>
<td>C(n=6) 3.25</td>
<td>3.25</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 4.02</td>
<td>4.08</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group; Total possible scores: CINS=20; SEB=5; SMQII=5

**CINS.**

Twenty test items in the CINS were categorized into 10 main ideas with two question items per category. Students were given a score of 0 for an incorrect response to a test item and a 1 for a correct response. Scores for each of the main ideas range from 0 to 2. Overall student results for this survey were very similar and can be found in the Table C2 in Appendix C2.

Students in the ECO+E class showed an increase in test score mean average from pre- to posttest in 8 of the 10 main ideas. Recognizing that ecosystems have limited
resources is the main idea with the greatest difference in mean (1.00) from pre- to posttest scores for this class. The ECO class showed the greatest increase in understanding of the origin of species in mean difference (1.16) from the pre- to posttest. The largest difference in mean scores between the ECO and ECO+E groups was in differential survival (0.50). The ECO+E class had a mean increase of 0.83, while the ECO class decreased in mean scores by -0.33 from pre- to posttest.

**SEB.**

Students in both classes had mixed results on the SEB survey that measured four epistemological dimensions. Scores in this survey range can range from 1-5 with 5 indicating the greatest level of epistemological development. In the ECO class, students scores increased in scientific epistemological beliefs from the pre- to the posttest in three of the four measured dimensions, Certainty (+0.27), Development (+0.22), and Justification (+0.33). In both classes, this epistemological dimension showed the largest increase in both classes. Students in the ECO+E class showed an increase in only one dimension: Source. ECO+E posttest differences in mean for Certainty and Development were less than - 0.1. Student decreases in mean scores in the Justification dimension was -0.24. This was the largest decrease in mean difference. Table 10 summarizes the SEB survey results for both classes in all four measured dimensions of epistemological development.
Table 10

**SEB Dimensions**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Pretest Mean</th>
<th>Posttest Mean</th>
<th>Difference in Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>C(n=6)</td>
<td>4.03</td>
<td>3.90</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>3.76</td>
<td>4.00</td>
</tr>
<tr>
<td>Certainty</td>
<td>C(n=6)</td>
<td>3.94</td>
<td>4.22</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>4.25</td>
<td>4.19</td>
</tr>
<tr>
<td>Development</td>
<td>C(n=6)</td>
<td>4.33</td>
<td>4.55</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>4.50</td>
<td>4.41</td>
</tr>
<tr>
<td>Justification</td>
<td>C(n=6)</td>
<td>4.01</td>
<td>4.35</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>4.41</td>
<td>4.16</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group; Difference in Mean (post-pre).

**SMQII.**

The SMQII measured students' science motivations in five component areas, intrinsic motivation, self-determination, self-efficacy, career, and grade motivations. Scores can range from 1 to 5, with 5 indicating the greatest level of motivation. Student results in both classes were mixed. Only one component, career motivation, showed increases from pre- to posttest in both classes. The ECO class showed decreases in all mean scores in three motivational components. Mean scores increased in career motivation (+0.26) and self-determination (+0.23) motivational components. The mean differences between pre and posttests in self-efficacy were less than 0.05 for both groups of students. Students in the ECO+E declined in motivation in two components self-determination (-0.10) and grade motivation (-0.13). Student gains in motivation were
intrinsic motivation (+0.23), self-efficacy (+0.10), and career motivation (+0.23). Table 11 shows the mean results of the SMQII broken down into the five motivational components by class.

Table 11

<table>
<thead>
<tr>
<th>SMQII Components</th>
<th>Pretest Mean</th>
<th>Posttest Mean</th>
<th>Difference in Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic Motivation</td>
<td>C(n=6) 3.16</td>
<td>E(n=6) 3.76</td>
<td>-0.10</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 3.76</td>
<td>E(n=6) 4.00</td>
<td>0.23</td>
</tr>
<tr>
<td>Self-Determination</td>
<td>C(n=6) 2.63</td>
<td>E(n=6) 3.76</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 3.76</td>
<td>E(n=6) 3.66</td>
<td>-0.10</td>
</tr>
<tr>
<td>Self-Efficacy</td>
<td>C(n=6) 3.50</td>
<td>E(n=6) 3.83</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 3.83</td>
<td>E(n=6) 3.93</td>
<td>0.10</td>
</tr>
<tr>
<td>Career Motivation</td>
<td>C(n=6) 2.90</td>
<td>E(n=6) 4.16</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 4.16</td>
<td>E(n=6) 4.40</td>
<td>0.23</td>
</tr>
<tr>
<td>Grade Motivation</td>
<td>C(n=6) 4.04</td>
<td>E(n=6) 4.54</td>
<td>-0.37</td>
</tr>
<tr>
<td></td>
<td>E(n=6) 4.54</td>
<td>E(n=6) 4.41</td>
<td>-0.13</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group; Difference in Mean (post-pre).

**Individual student results.**

All students in the selected subset of this study had increased scores on the CINS. Students scoring the lowest on the pretest had the largest gain in scores on the posttest. These same students had some of the highest posttest scores in both classes. Ann had a pretest score of 5 and a posttest score of 14 in the ECO+E class. Her score increased by 9 points from 25% to 70%. Chris scored a 6 on the pretest and a 14 on the posttest from
the ECO class. His score increased from a 30% to a 70%. Four students, Ann, Brea, Paige, and Chris at minimum, doubled their pretest CINS scores. These students represent over one-third of the students in this study. Seven student's scores showed an increase posttest score of only 1 to 3 correct answers. Stuart was the only student who did not increase his posttest score to a minimum of 50% or 10. Andrew's pre- and posttest score only increased by 1 item. Individual mean and total scores all three surveys for each student in this study are given in Table C2 in Appendix C.

Student scores in the SEB and SMQII were mixed with small increases or decreases in mean (< 0.65) from pre- to posttest. In the SMQII, only two students, Don and Stuart in the ECO class showed increases in epistemological development and science motivation. Many students showed minor decreases in both SEB and SMQII scores from pre- to posttests. One student, Mike, showed no increase or decrease in beliefs or motivation scores.

Written student artifacts constitute a large majority of the data collected in this study. Student explanations reveal evolutionary conceptions and beliefs. The results of these explanations in Part 2 follow.

**Part 2: Student Explanations**

Student written explanations were obtained from tasks included in two ecology, formative assessments during the instructional unit. Tasks 1 and 2 were completed during the second week with tasks 3 and 4 near the end of the 4th week (Table 1). All four tasks were included at the end of two formative assessments (Population Quiz 1 and 2). These assessments measured student knowledge of population growth, limited
resources, and population stability around the carrying capacity with multiple choice questions, graph interpretations, and short responses. Population Quiz 2 can be found in Appendix B4. Task explanations required applications of concepts in natural selection and were rated as descriptive, teleological, proximate, or evolutionary.

Explanations should have contained components of natural selection, but that was not the criteria for rating explanations. Descriptive explanations simply provided a narrative account of the task. Teleological explanations gave purposeful intentions or goals to reasoning for the biological process. Proximate explanations provided physiological or mechanistic accounts of the task phenomena. Explanations were rated evolutionary when they provided scientific reasoning for population changes with time. In addition to rating, explanations were examined student's ontological and epistemological status. All student written artifacts and coding can be found in Appendix C1.

Summary of class data.

Students provided a range of explanations for the four tasks. The ECO+E class decreased teleological explanations from 6/12 (50%) in the second week to 4/12 (33%) the fourth week. The numbers of teleological explanations in the ECO class remained constant at 4/12 (33%) throughout the duration of the study. Ontologically, students' written explanations revealed differing characteristics of direct-process ontology. Several students gave consistent explanations in all four tasks. Bill (ECO+E) consistently constructed evolutionary explanations in all four tasks. Chris (ECO) made proximate explanations for all tasks. Two students, Andrew (ECO+E) and Stuart (ECO) provided
teleological explanations for all four tasks. The majority of students created a variety of
explanations. Table 12 presents the results of all four explanations for each student.

Table 12

<table>
<thead>
<tr>
<th>Student</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew (E)</td>
<td>Teleological</td>
<td>Teleological</td>
<td>Teleological</td>
<td>Teleological</td>
</tr>
<tr>
<td>Ann (E)</td>
<td>Description</td>
<td>Proximate</td>
<td>Proximate</td>
<td>Proximate</td>
</tr>
<tr>
<td>Bill (E)</td>
<td>Evolutionary</td>
<td>Evolutionary</td>
<td>Evolutionary</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>Brea (E)</td>
<td>Teleological</td>
<td>Teleological</td>
<td>Proximate</td>
<td>Teleological</td>
</tr>
<tr>
<td>Paige (E)</td>
<td>Proximate</td>
<td>Teleological</td>
<td>Proximate</td>
<td>Teleological</td>
</tr>
<tr>
<td>Zena (E)</td>
<td>Evolutionary</td>
<td>Teleological</td>
<td>Evolutionary</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>Chris (C)</td>
<td>Proximate</td>
<td>Proximate</td>
<td>Proximate</td>
<td>Proximate</td>
</tr>
<tr>
<td>Don (C)</td>
<td>Description</td>
<td>Teleological</td>
<td>Proximate</td>
<td>Teleological</td>
</tr>
<tr>
<td>Kevin (C)</td>
<td>Proximate</td>
<td>Proximate</td>
<td>Evolutionary</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>Lisa (C)</td>
<td>Proximate</td>
<td>Teleological</td>
<td>Proximate</td>
<td>Proximate</td>
</tr>
<tr>
<td>Mike (C)</td>
<td>Proximate</td>
<td>Proximate</td>
<td>Teleological</td>
<td>Proximate</td>
</tr>
<tr>
<td>Stuart (C)</td>
<td>Teleological</td>
<td>Teleological</td>
<td>Teleological</td>
<td>Teleological</td>
</tr>
</tbody>
</table>

Notes: (E)=ECO+E/experimental group; (C)= ECO/control group; Names are pseudo
names.

Each class had 24 tasks in this study. There were seven (29%) evolutionary
responses created in the ECO+E class. The ECO class constructed 13(54%) proximate
explanations. Both classes gave 12(50%) teleological explanations for various tasks.
The ECO+E class had 10/24 (42%) teleological explanations, while the ECO class had 8/24 (33%). Table 13 shows the number and type of explanations students gave for these tasks in the second week and the fourth week.

Table 13

<table>
<thead>
<tr>
<th>Type</th>
<th>Week 2 Task 1</th>
<th>Week 2 Task 2</th>
<th>Week 2 Task 3</th>
<th>Week 2 Task 4</th>
<th>Week 4 Task 2</th>
<th>Week 4 Task 3</th>
<th>Week 4 Task 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolutionary</td>
<td>(0, 2)</td>
<td>(0, 1)</td>
<td>(1, 2)</td>
<td>(1, 2)</td>
<td>(2, 7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximate</td>
<td>(4, 1)</td>
<td>(3, 1)</td>
<td>(3, 3)</td>
<td>(3, 1)</td>
<td>(13, 6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teleological</td>
<td>(1, 2)</td>
<td>(3, 4)</td>
<td>(1, 1)</td>
<td>(2, 3)</td>
<td>(8, 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Explanation</td>
<td>(1, 1)</td>
<td>(0, 0)</td>
<td>(0, 0)</td>
<td>(0, 0)</td>
<td>(1, 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: (C,E) C=ECO/control group; E= ECO+E/experimental group

**Individual explanations.**

Individual student explanations, coding (italics), and interpretations can be found in Appendix C1. Examples of evolutionary explanations include Zena, Kevin, and Bill. These students stated or implied an understanding that genes contribute to traits, individuals within populations have differing survival abilities, and populations change over time. However, their explanations revealed that they believed natural selection a direct-process ontology rather than an emergent process.

Tasks 3 and 4 provided minimal information about the populations (Table 1) in the task. The questions demanded students explain adaptations like camouflage or leaf-like features without any specific discussions of populations. Students provided more
numerous teleological explanations in these two tasks than in Tasks 1 and 3. Seven of the 12 (58%) students gave teleological explanations, in Task 2 with 5(42%) in Task 4. Andrew, Brea, and Paige in the ECO+E class and Stuart and Don in the ECO class gave teleological explanations for both tasks. These explanations may have included proximate or evolutionary causation, but expressed goal or need-based conceptions.

Several students progressed toward more evolutionary explanations over the duration of the study. For example, two students provided simple descriptions of the phenomena in Task 1 and formed proximate explanations for Task 3 in the fourth week. Table 14 is a summary of the numbers of students whose explanations showed progression from the second week to the fourth week.

Table 14

<table>
<thead>
<tr>
<th>Student's Explanation Progressions</th>
<th>Task 1 to Task 3</th>
<th>Task 2 to Task 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Explanation Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teleological to Evolutionary</td>
<td>(0, 0)</td>
<td>(0, 1)</td>
</tr>
<tr>
<td>Proximate to Evolutionary</td>
<td>(1, 0)</td>
<td>(1, 0)</td>
</tr>
<tr>
<td>Teleological to Proximate</td>
<td>(0, 1)</td>
<td>(1, 0)</td>
</tr>
<tr>
<td>No Explanation to Evolutionary</td>
<td>(0, 0)</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>No Explanation to Proximate</td>
<td>(1, 1)</td>
<td>(0, 0)</td>
</tr>
</tbody>
</table>

Notes: (C,E) C=control group; E=experimental group

Other student's explanations showed progression in their explanations. Zena (ECO+E) created a teleological explanation for Task 2 in the second week when she implied non-random intent to mutations. She stated that mutations may happen so that an
organism can better blend into the environment. In Task 4 she composed an evolutionary explanation by not assigning intent or goals in her explanation and including population change with time. Lisa (ECO) constructed a teleological explanation in the second week by asserting need to adaptations. Her explanation in the fourth week gave proximate causation to adaptations. It was not evolutionary because she did not give explanation or reasoning for the adaptation. She explained how an organism has the features (genes), but did not explain why.

Student explanations revealed underpinning presuppositions, in addition to teleological, proximate, and evolutionary conceptions. Additional data from pre- and post-argument reflections uncover students' conceptions, scientific epistemological beliefs, and motivations. Results from these reflections in Part 3 follow.

**Part 3: Student Reflections**

Student reflections revealed student's ontology, epistemology, and motivations prior to and following student argumentation after completion of two inquiries, *The Galápagos Finches*© (bguile.northwestern.edu) and *Bug Hunt Camouflage* © (Novak & Wilensky, 2006; Wilensky, 1999). Reflection questions queried students' existing conceptions, beliefs about their learning, and science motivations. Reflection responses probed students' beliefs relating to their experiences with these two inquiries and the argumentation process using a multidimensional perspective meshing constructs in the CRKM with epistemological dimensions and motivational components from surveys.

Student reflections contain two distinct parts. Pre- and post-argument questions checked for student ontological and epistemological suppositions and included the two
core investigative focus questions. The ECO+E class had three additional intervention questions. Post-argument reflections queried student’s epistemic beliefs and science motivations reflection questions and were identical for both classes. Eleven responses for this part coded scientific epistemological beliefs with seven responses for motivations for each student (see Appendix B7 for coding categories and notes). Responses were coded and rated as high or low according dimension and component criteria and the degree to which they supported assertions and ideas.

Part 3 results begin with an overall summary of the ontological, epistemological and motivational statue of the classes. This is followed with detailed results concentrating on student understanding of scientific conceptions with pre- and post-argument questions. Reflection questions for this section were the investigative focus questions for both inquiries. These questions plus additional investigative questions explicitly designed to elicit evolutionary conceptions were included in the ECO+E class reflections. Data were coded and analyzed for ontological status and epistemological suppositions that include; strength, coherence, and commitments of existing conceptions. The next section consists of post-argument results that report students’ epistemic beliefs regarding their arguments, particularly their reasoning behind choosing evidence and their ideas about scientific knowledge generation. In the last section students’ self-motivations, along with career and grade motivations are reported.

**Summary of ontological, epistemological, and motivational status.**

Students in the ECO+E class showed more direct-process ontology in both pre- and post-argument claims and explanations to reflective questions. Students in both
classes demonstrated enrichment and revision of conceptions in population ecology.
Student responses to reflection questions in the ECO+E and ECO classes showed similar epistemological development. Students in the ECO+E class scored high in beliefs development in all four epistemological dimensions. In the ECO class, Source dimension was low with 2/6 (33%) scoring low on development. Reflection responses in the ECO+E class indicated higher self and career/grade motivations than students in the ECO class. Students in the ECO class consistently scored lower development on career/grade motivations.

**Ontological and epistemological status.**

Results for both classes were consistent for both pre- and post-argument responses for both inquiries. All students demonstrated enrichment or revision of conceptions in population ecology after *The Galápagos Finches*© (bguile.northwestern.edu) inquiry in the ECO class. Students described populations in terms of the present using appropriate ecological conceptions. In the second inquiry, *Bug Hunt Camouflage*© (Novak & Wilensky, 2006; Wilensky, 1999), the investigative focus question forced students to explain the influence of environmental factors on populations over time. Four students constructed claims that revealed suppositions that were characteristic of direct-process ontology in their pre-argument reflections, while three students' responses on the post-argument gave claims with attributes of direct-process ontology.

Students in the ECO+E class constructed more claims and explanations that showed direct-process ontology in both pre- and post-arguments for both inquiries.
Intervention questions probed perspicaciously for student conceptions on evolutionary processes with 'why' questions. Five students consistently responded to reflection questions with claims and explanation that revealed direct-process ontology. One student (Ann) focused only the ecological conceptions and descriptions in her responses to the reflection questions in both inquiries. Table 15 presents class results for both the ECO and ECO+E classes. Individual responses can be found in student Appendix C1.

Table 15

<table>
<thead>
<tr>
<th>Class Conceptual Status</th>
<th>Measure</th>
<th>Description/Enrichment/Proximate</th>
<th>Direct-Process Ontology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Galápagos Finches</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>C(n=6)</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Argument</td>
<td>E(n=6)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>After</td>
<td>C(n=6)</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Argument</td>
<td>E(n=6)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><strong>Bug Hunt</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>C(n=6)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Argument</td>
<td>E(n=6)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>After</td>
<td>C(n=6)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Argument</td>
<td>E(n=6)</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group

The second pre- and post-argument reflection responses for the bug modeling inquiry results revealed differences in ontological suppositions. The single, investigative-focus question was essentially the same for both inquiries, but more general than the
focus question questions for the finches. The general investigative question required explanations for changes in a bug population over time. Direct-process ontology was reflected in claims and explanations from students the ECO+E class remained coherent after both inquiry arguments. At least three students (50%) from the ECO class disclosed direct-process statuses in either the pre- and post-argument claims.

Scientific epistemological beliefs

The second part of the student reflections were designed to probe student's science beliefs and motivations after post-inquiry argumentation for both *The Galápagos Finches*© (bguile.northwestern.edu) and *Bug Hunt Camouflage*©(Novak & Wilensky, 2006; Wilensky, 1999) inquiries. Epistemological suppositions regarding these inquiries, or task message, were coded and analyzed for comprehensibility, plausibility, coherence, and rhetorical drive, where applicable and perceivable by the researcher. In addition, student's disclosed their scientific epistemological beliefs in responses to 11 questions to measure dimensions of Source, Certainty, Development, and Justification. Beliefs development for these specific epistemological dimensions were coded and rated as high or low. Students rated high beliefs by articulating and rationalizing their claims, evidence, and reasoning (See Appendix B7 for coding categories and notes). Ratings of high beliefs received a score of 1, and low beliefs received a 0 score. The highest possible score for science beliefs is 11.

Overall, student reflections varied in epistemological development in both the ECO and ECO+E classes. One dimension, Source, had the lowest scores with 2/6 (67%) students in the ECO class scoring low beliefs development after the bug modeling
inquiry. Conversely, in this same, all six students (100%) showed high development in the *Justification* dimension in the finch inquiry. Table 16 shows the class results with samples of reflection questions for selected dimensions.

Table 16

<table>
<thead>
<tr>
<th>Class Epistemological Status</th>
<th>Galápagos Finches ©</th>
<th>Bug Hunt Camouflage ©</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td>Q- Is your claim scientific? Explain</td>
<td></td>
</tr>
<tr>
<td>C(n=6)</td>
<td>3 3</td>
<td>2 4</td>
</tr>
<tr>
<td>E(n=6)</td>
<td>4 2</td>
<td>5 1</td>
</tr>
<tr>
<td><strong>Certainty</strong></td>
<td>Q- Did your claim change when you saw conflicts in data? Explain. Dimension</td>
<td></td>
</tr>
<tr>
<td>C(n=6)</td>
<td>3 3</td>
<td>4 2</td>
</tr>
<tr>
<td>E(n=6)</td>
<td>3 3</td>
<td>3 3</td>
</tr>
<tr>
<td><strong>Justification</strong></td>
<td>Q- Identify patterns in evidence and give specific examples.</td>
<td></td>
</tr>
<tr>
<td>C(n=6)</td>
<td>6 0</td>
<td>4 2</td>
</tr>
<tr>
<td>E(n=6)</td>
<td>3 3</td>
<td>5 1</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group.

**Student motivations.**

Four reflection questions queried for motivational components of self-efficacy, relatedness or personal relevance, self-determination or autonomy, and intrinsic motivation or need for cognition. Responses were analyzed for component attributes and contextual interpretation of student's intent through their written responses. These
responses were coded and rated as high or low, using scores of 1 or 0 as before. These components were consolidated as *Self-Motivations* for convenience of analysis. Three career and grade motivation responses were coded high or low based on student's support for their grade assertions and personal relevance.

Students in the ECO+E class responses indicated higher self and career/grade motivations than students in the ECO class. Students in the ECO class consistently had lower ratings on career and grade motivations after both arguments. Three students (Chris, Don, and Lisa) responses were coded low in motivations in these components. Students in the ECO+E class consistently rated high (83%) in self-motivations after both arguments. These students also showed gains in career and grade motivations from the first to the second argument. All student individual coding and notes can be found in Appendix C1. Summarized class results are presented in Table 17.

Table 17

<table>
<thead>
<tr>
<th>Class Motivational Status</th>
<th>Self-Motivations</th>
<th>Career/Grade Motivations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><em>Galápagos Finches</em>©</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C(n=6)</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>E(n=6)</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td><em>Bug Hunt Camouflage</em>©</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C(n=6)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>E(n=6)</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes: C = ECO/control group; E = ECO+E/experimental group.
Table 18 shows a summary of student results from reflections for science beliefs and motivations. Two students from this class, Chris and Don, showed lower scores in development of science beliefs than other members in this study.

Table 18

<table>
<thead>
<tr>
<th>Student</th>
<th>Science Beliefs</th>
<th>Science Motivations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S/J(7)</td>
<td>C/D(4)</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Andrew (E)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Ann (E)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Bill (E)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Brea (E)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Paige (E)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Zena (E)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Chris (C)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Don (C)</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Kevin (C)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Lisa (C)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Mike (C)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Stuart (C)</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group; S/J=source/justification dimension; C/D=certainty/development dimension; SM=self-motivations; C/GM=career/grade motivation; Parentheses=(number of questions); Student names are pseudo names.

Student reflection results disclosed pre- and post-argument conceptions, science beliefs, and science motivations. Part 4 of this chapter presents results from three
concept mapping tests used interpretively to construct student mental models. In addition to declarative knowledge, concept maps reveal procedural knowledge through concept linkage and overall structure complexity.

**Part 4: Concept Maps**

Concept maps were analyzed both quantitatively and qualitatively to ascertain student's conceptual and epistemological frameworks. Students in both the ECO and ECO+E groups constructed two different types of concept maps using 12 concepts in population ecology and evolution. Two self-constructed maps (C-maps) were used as the pretest and as a final test (6-Week). Students were free to choose relationships and construct linking phrases for concepts. The posttest, given at the end of the instructional unit, was a hybrid map (H-map). Students used given cognitive maps constructed from similarity ratings and created linking phrases to fit the connected concepts.

Quantitative scores for students were determined by scoring each proposition for scientific accuracy. All propositions were scored from 0 (irrelevant or ontologically incorrect) to 3 (correct and scientific). A score of 1 was given when a student tried to make a connection between two concepts, but it was incorrect. A score of 2 was given for nearly correct scientific assertions, but were absolute because the proposition did not all allow for exceptions or chance. A proposition score of 3 indicates an accurate and correct scientific declaration. Total proposition score is the average of all proposition scores. Total accuracy score is the sum of all the proposition scores. Only propositions with a score of 3 were considered scientific and met the criteria for screening for evolutionary tenets. Table 19 shows examples of student propositions and scoring.
Table 19

<table>
<thead>
<tr>
<th>Score</th>
<th>Proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Limiting factors influence variation in a species, causing a need for differential survival.</td>
</tr>
<tr>
<td>1</td>
<td>Changing environment influences heredity and cause changes in generations.</td>
</tr>
<tr>
<td>2</td>
<td>Individual organisms inherit mutations.</td>
</tr>
<tr>
<td>3</td>
<td>Individual organisms have differential survival in changing environments.</td>
</tr>
</tbody>
</table>

**Class mean scores.**

Students in both the ECO and ECO+E classes showed increases in propositional accuracy and total numbers of propositions constructed from the pretest to the final (6 Week) test. Student propositional accuracy scores showed the largest increase from the pre-test to the final test with an increase in mean difference of at least 13 points. The ECO class had a mean increase from the posttest to the final test of 2.7, while the ECO+E class had a mean increase of 1.4. The number of propositions constructed showed the largest increase from the pre- to the posttest in both classes with mean difference gains of 7.5 (ECO) and 6.8 (ECO+E). Both classes showed decreases in the number of propositions constructed from the posttest to the final test. The ECO+E class showed the largest decrease from 18.8 to 14.7 propositions (-4.1 mean difference), while the ECO class showed a decline of 18.5 to 17.5 (-1.0 mean difference).

The ECO+E class showed an increase (0.6) in the mean propositional quality from the pretest mean score of 1.7 to the final test mean score of 2.3. The ECO class showed no increases in these scores. The means of the pre- and posttest propositional
scores for the ECO class showed a decrease from 2.0 to 1.8, while the ECO+E class remained at a mean of 1.7. Scores for all three assessments for the ECO and ECO+E groups are presented in Table 20.

### Table 20

*Concept Map Scoring Results*

<table>
<thead>
<tr>
<th></th>
<th>P Mean</th>
<th>PT Mean</th>
<th>MD (PT-T)</th>
<th>FT Mean</th>
<th>MD (FT-P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposition C(n=6)</td>
<td>22.5</td>
<td>33.0</td>
<td>10.5</td>
<td>35.7</td>
<td>13.2</td>
</tr>
<tr>
<td>Accuracy E(n=6)</td>
<td>20.7</td>
<td>32.3</td>
<td>11.6</td>
<td>33.7</td>
<td>13.0</td>
</tr>
<tr>
<td>Proposition C(n=6)</td>
<td>2.0</td>
<td>1.8</td>
<td>-0.2</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Score E(n=6)</td>
<td>1.7</td>
<td>1.7</td>
<td>0.0</td>
<td>2.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Proposition C(n=6)</td>
<td>11.0</td>
<td>18.5</td>
<td>7.5</td>
<td>17.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Number E(n=6)</td>
<td>12.0</td>
<td>18.8</td>
<td>6.8</td>
<td>14.7</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group; P=pretest; PT=posttest; MD=mean difference; FT=final test

### Ontological and Epistemological Status.

Students’ proposition scores from 0 to 2 were designated synthetic propositions, since they contained inaccurate, naive, or absolute declarations. Pre- and posttest results in both the ECO and ECO+E classes indicate that the majority of constructed propositions were synthetic. The number and proportion of synthetic propositions increased from the pre- to posttest in both classes. Both the ECO and ECO+E classes showed a decrease in the proportion of synthetic to scientific propositions from the pre- to final test, however. Students in the ECO+E class increased the number of scientific propositions constructed from the pretest (39%) to the final test (60%) with an overall
increase of 21%. The ECO class increased their number of scientific propositions by 4% overall. Table 21 reports class totals of synthetic and scientific propositions (see Appendix C1 for individual student scientific propositions).

Table 21

<table>
<thead>
<tr>
<th>Propositions</th>
<th>Synthetic</th>
<th>Scientific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>C(n=66)</td>
<td>37 (56%)</td>
</tr>
<tr>
<td></td>
<td>E(n=72)</td>
<td>44 (61%)</td>
</tr>
<tr>
<td>Posttest</td>
<td>C(n=111)</td>
<td>75 (68%)</td>
</tr>
<tr>
<td></td>
<td>E(n=113)</td>
<td>75 (66%)</td>
</tr>
<tr>
<td>Final Test</td>
<td>C(n=103)</td>
<td>54 (52%)</td>
</tr>
<tr>
<td></td>
<td>E(n=89)</td>
<td>36 (40%)</td>
</tr>
</tbody>
</table>

Notes: C = ECO/control group; E = ECO+E/experimental group; n = number of propositions

**Class evolution propositions.**

Scientific propositions were examined for evolutionary content on the components of the mechanism of natural selection (Mayr, 1998, p. 219). These components included exponential growth, populations at carrying capacity, limited resources/factors, differential survival, variations, and inheritance. Overall both classes showed increases in the proportion of evolutionary propositions constructed. Evolutionary propositions created in the ECO+E class rose from 16/28 (57%) to 42/53 (79%) pre- to final test. The total numbers of evolutionary propositions decreased in the
ECO class from 21/29 (72%) to 35/49 (71%). The total numbers of evolutionary propositions and percentages are shown in Table 22.

Table 22

<table>
<thead>
<tr>
<th>Propositions</th>
<th>Scientific</th>
<th>Evolutionary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>C(n=66)</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>E(n=72)</td>
<td>28</td>
</tr>
<tr>
<td>Posttest</td>
<td>C(n=111)</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>E(n=113)</td>
<td>38</td>
</tr>
<tr>
<td>Final Test</td>
<td>C(n=103)</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>E(n=89)</td>
<td>53</td>
</tr>
</tbody>
</table>

Notes: C = ECO/control group; E = ECO+E/experimental group; n = number of propositions.

**Individual evolution propositions.**

Five of six students showed an increase of three evolutionary propositions (minimum of 20%) from the pre- to final test. The largest gain in evolutionary proposition construction was Zena who increased from 0 to 7 from the pre- to the posttest. This gain reflects an increase in overall proportion of evolutionary propositions from 0 of 11 total propositions (0%) on the pretest to 7 evolutionary of 23 total propositions (30%) on the posttest to 7 evolutionary of 12 total propositions (58%) on the final test. One student (Bill) showed the lowest gain from 7 evolutionary propositions of 12 total propositions (58%) in the pretest to 11 evolutionary propositions of 18 total propositions (61%) on the final test. One student (Paige) showed no increase in
evolutionary proposition construction. She constructed 3 evolutionary propositions of 15 total propositions (20%) on the pretest while she constructed 3 evolutionary propositions of 14 total propositions (21%) in the posttest.

During the intervention, four students in the ECO+E class showed increases in the proportion of evolutionary propositions they constructed from the pre- to the posttest. Two students in the ECO+E class (Brea and Bill) showed declines in the proportions of evolutionary propositions, though Brea did construct two additional evolutionary propositions and Bill's evolutionary proposition number remained constant at seven.

Student's construction of evolutionary propositions in the ECO class showed variable results. During the intervention unit, two of six students showed increases in evolutionary proposition construction from the pre-to posttest (Chris and Mike). Mike showed the largest increase of evolutionary proposition construction during the study. In his pretest, he constructed of 4 evolutionary propositions of 12 total propositions (33%) and 9 evolutionary propositions of 22 total propositions (41%) on the posttest. Chris increased from 2 evolutionary propositions of 9 total propositions (22%) to 3 evolutionary propositions of 13 total propositions (23%).

Overall, four students in the ECO class showed decreases in evolutionary proposition proportions during this study period from pre- to posttest. Two students in the ECO class (Kevin and Lisa) showed decreases in their construction of evolutionary propositions from the pre- to posttest (22%, 17%) and final test (30%, 18%). While Stuart increased from 4 evolutionary propositions of 12 total propositions (33%), the
proportion of his evolutionary propositions to total propositions decreased with 6 evolutionary propositions to 24 total propositions (25%).

Other students in the ECO class showed mixed results. One student (Don) showed a decrease from 4 evolutionary propositions of 13 total propositions (31%) in the pretest to 1 evolutionary proposition of 16 total propositions (6%). Two students (Kevin and Lisa) did not show any changes in their construction of evolutionary concepts from the pre- to the posttest. Since both students constructed more total propositions on the posttest, their proportions of evolutionary propositions decreased. Kevin constructed 4 evolutionary propositions of 11 total propositions (36%) on the pretest and 4 evolutionary propositions of 18 total propositions (22%) on the posttest. Lisa constructed 3 evolutionary propositions of 9 total propositions (33%) on the pretest, 3 evolutionary propositions of 18 total propositions (17%) on the posttest. Five of six students in the ECO class showed increases in construction of evolutionary propositions from the pre- to final test. The largest increase (5) in evolutionary propositions was Mike with a pretest and final test proposition proportion gains of 12% (33% to 45%). Individual scores are presented in Appendix C1.

Class Ontologies and Epistemologies in Natural Selection

Student propositions were further screened for specific natural selection tenets or inferences in natural selection. These propositions (Evo-NS) contained declarations of genetic variation in individuals, the heritability of genetic variations, the differential survival of individuals, and change over generations. The ECO+E constructed 19 (50%) of 38 total scientific propositions were Evo-NS in three of the four screened tenets of
natural selection in their posttest. The final test showed that the ECO+E class constructed greater proportions of Evo-NS propositions with 29/53 (55%) in the four specific tenets of natural selection. Table 23 shows the numbers of Evo-NS proposition results for both classes.

Table 23

<table>
<thead>
<tr>
<th>Natural Selection Tenets</th>
<th>Posttest</th>
<th>Final Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetic Variation</td>
<td>C(n=36)</td>
<td>2 (6%)</td>
</tr>
<tr>
<td></td>
<td>E(n=38)</td>
<td>7 (18%)</td>
</tr>
<tr>
<td></td>
<td>C(n=36)</td>
<td>4 (11%)</td>
</tr>
<tr>
<td></td>
<td>E(n=38)</td>
<td>5 (13%)</td>
</tr>
<tr>
<td></td>
<td>C(n=36)</td>
<td>6 (17%)</td>
</tr>
<tr>
<td></td>
<td>E(n=38)</td>
<td>7 (18%)</td>
</tr>
<tr>
<td></td>
<td>C(n=36)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E(n=38)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>C(n=49)</td>
<td>5(10%)</td>
</tr>
<tr>
<td></td>
<td>E(n=53)</td>
<td>4(8%)</td>
</tr>
<tr>
<td></td>
<td>C(n=49)</td>
<td>4(8%)</td>
</tr>
<tr>
<td></td>
<td>E(n=53)</td>
<td>9(17%)</td>
</tr>
<tr>
<td></td>
<td>C(n=49)</td>
<td>1(2%)</td>
</tr>
<tr>
<td></td>
<td>E(n=53)</td>
<td>9(17%)</td>
</tr>
<tr>
<td></td>
<td>C(n=49)</td>
<td>2(4%)</td>
</tr>
<tr>
<td></td>
<td>E(n=53)</td>
<td>7(13%)</td>
</tr>
</tbody>
</table>

Notes: C = ECO/control group; E = ECO+E/experimental group; n = number of evolutionary propositions; parentheses=percent of n.

Student propositions in natural selection.

Student propositions were analyzed for ontological and epistemological suppositions. Three main synthetic conceptions were identified in both classes. These conceptions were (a) heredity as matter passed from generation to generation, (b) genetic variations as things, and (c) changing environments causing needed mutations. Both the ECO and ECO+E classes showed fewer numbers of the identified synthetic conceptions from the posttest to final test in two of the three synthetic conceptions.
Table 24 gives the number of propositions constructed with one or more of these synthetic, alternate conceptions.

### Table 24

**Number of Identified Alternate Conceptions**

<table>
<thead>
<tr>
<th></th>
<th>Posttest C(n=75)</th>
<th>Final Test C(n=54)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E(n=75)</td>
<td>E(n=36)</td>
</tr>
<tr>
<td>Heredity as</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matter</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Genetic Variation as</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Matter</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Changing Environments</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Cause necessary Mutations</td>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>

Notes: C = ECO/control group; E = ECO+E/experimental group

Examples of two students' proposition progression for natural selection tenets or inferences constructed as synthetic propositions in both classes in Table 25.

Epistemological suppositions show specific theory revision or ontological shifts for all four student examples.
Table 25

**Student Supposition Progressions**

<table>
<thead>
<tr>
<th></th>
<th>Natural Selection Tenet -Inheritance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Andrew (E)</strong></td>
<td></td>
</tr>
<tr>
<td>Pretest Proposition</td>
<td>Heredity is passed through the genes of your parents.</td>
</tr>
<tr>
<td>Supposition</td>
<td>Heredity is matter; heredity not viewed as a process</td>
</tr>
<tr>
<td>Posttest Proposition</td>
<td>Heredity is passed down to the offspring through reproduction.</td>
</tr>
<tr>
<td>Supposition</td>
<td>Heredity is matter; heredity not viewed as a process</td>
</tr>
<tr>
<td>Final Test Proposition</td>
<td>Reproduction can pass traits down through a process called heredity.</td>
</tr>
<tr>
<td>Supposition</td>
<td>Heredity is a process; Revision or model transformation-specific theory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Natural Selection Tenet -Genetic Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kevin (C)</strong></td>
<td></td>
</tr>
<tr>
<td>Pretest Proposition</td>
<td>Genetic variations create mutations that increase survival rates.</td>
</tr>
<tr>
<td>Supposition</td>
<td>Genetic variations is thing; synthetic conception</td>
</tr>
<tr>
<td>Posttest Proposition</td>
<td>Genetic variations change the gene.</td>
</tr>
<tr>
<td>Supposition</td>
<td>Genetic variations is thing; synthetic conception</td>
</tr>
<tr>
<td>Final Test Proposition</td>
<td>Genetic variations occur in individual organisms.</td>
</tr>
<tr>
<td>Supposition</td>
<td>Simple Revision or transformation of model-specific theory</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group. Names are pseudo names.

**Concept Map Structure**

Student concept maps were qualitatively evaluated on structural complexity (See Figure 4). Student C-maps in the pretest had more variety of structural complexity in both the ECO and ECO+E classes. Since the posttest concept map was an H-map, all students were given a cognitive map from similarity ratings and these maps showed network structure linking concepts, except for one student (Paige) in the ECO+E class. The final map was a C-map that students constructed and these show more variety in structural types, a minimum of 67% (4/6) students in both classes constructed network structure
Table 26 presents the results of analysis for concept map structures for both classes.

Table 26

<table>
<thead>
<tr>
<th>Type</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Final Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>C(n=6)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Circular</td>
<td>C(n=6)</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Hub/Spokes</td>
<td>C(n=6)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Tree</td>
<td>C(n=6)</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Network</td>
<td>C(n=6)</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>E(n=6)</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Notes: (C,E) C=ECO/control group; E= ECO+E/experimental group

A student example (Mike), Figure 3, shows the cognitive-associative map made from proximity matrix with Pathfinder algorithms (Schaneveldt, 1990). The map posttest required each student to mirror the structural links between concepts and create linking phrases to connect concepts to construct propositions. This sample shows how students could accurately reproduce the links and network structure of their cognitive map.
Figure 3. Student cognitive-associative map. Made with Version 6.2 of Pathfinder (Schaneveldt, 1990).

Mike's posttest H-map, Figure 4, was made with WebspirationClassroom© (Inspiration Software, Inc), as were all concept maps. His H-map reflects the structure of the cognitive-associative map, but has constructed propositions linking the concepts together.

Figure 4. Student H-map.

Since all students (but Paige) had network structures for the cognitive, associative maps, student finished posttest H-maps mirrored these complex designs. H-maps were
eliminated from students' personal accounts prior to the construction of the final C-map, so students were not able to copy these structures. Most of the final C-maps did not have the number of links to concepts, because the proposition count was lower in the final test. However some final C-maps (Mike) shown in Figure 5 showed similar linkages networks and complexity.

Figure 5. Final C-map.

Summary and Amalgamation of Data

This portion of the chapter forms a coherent, succinct summary of data. Since results were analyzed from a multidimensional perspective, findings from all four parts of this chapter are combined into three dimensions. This synthesis section begins by merging all results that monitor and record conceptual development in this study. Individual student synthesis of data can be found in Appendices C4 and C5.
**Ontological status.**

Class results showed that most students in the ECO+E class have various features of direct-process ontology in pre- and post-argument claims and explanations after *The Galápagos Finches*© (bguile.northwestern.edu) and *Bug Hunt Camouflage*© (Novak & Wilensky, 2006 Wilensky, 1999) inquiries. Students in this class revealed goal and intentional, direct-process ontology (5/6=83%) with coherence and commitment in responses. Students in the ECO class showed enrichment and revision in ecological conceptions with descriptions of populations in pre- and post-arguments after the finch inquiry. Results for pre- and post-argument following the bug modeling inquiry differed. At least 50% (3/6) of the students in the ECO class showed direct-process ontology presuppositions in their claims.

**Assessment results.**

Overall, both classes showed increases in CINS scores from the pre- to posttest. The ECO+E class difference in mean scores from pre-to posttest was 4.67. The class mean was 11.33 (20 possible) with posttest scores ranging from 10 to 14. In the ECO class the difference in mean scores from pre- to posttest was 3.83 with posttest scores ranging from 9 to 14 and class mean score of 11.50. Two formative quiz assessments (Appendix A4-Quiz 2) on ecological concepts at week 2 and 4 produced similar class mean scores. The ECO+E class results of the three concept mapping tests show increases in proposition accuracy, propositional scores, and numbers of propositions from the pretest through the final test. The ECO class showed increases in propositional accuracy and in the numbers of propositions written. Overall this class increased the number of
propositions written by 6.5, and the ECO+E class increased by 2.7 during that period.

Proposition scores increased from 1.7 to 2.3 from pre- to posttest in the ECO+E class.

Table 27 shows a summary of the assessment scores in this study.

Table 27

<table>
<thead>
<tr>
<th>Unit Assessment Scores Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>CINS</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>C</td>
</tr>
</tbody>
</table>

Note: (C)=ECO/control; (E)=ECO+E/experimental; M=mean; Q1=Quiz 1; Q2=Quiz 2; Prop=proposition; Pre=pretest; Post=posttest; Final=Final Test.

The numbers of synthetic, non-scientific propositions constructed in the ECO+E class decreased from 61% (44/72) on the pretest to 40% (36/89) on the final test. The ECO class showed a decrease in the numbers of synthetic propositions constructed from 56% (37/66) on the pretest to 54% (54/103) on the final test. The numbers of evolutionary propositions constructed from pre- to final tests increased in both classes. The number of evolutionary propositions constructed in the ECO+E class increased from 16/28 (57%) to 42/53 (79%) pretest to final tests. The total numbers of evolutionary propositions created in the ECO class decreased from 35/49 (72%) to 50/53 (71%) from pretest to final tests.

Student self-constructed C-maps had more variety in structural complexity in both the ECO and ECO+E classes on the pretest. Student cognitive maps made from proximity maps of similarity ratings formed predominately network structures. Students
mimicked this network structure on posttest H-maps. Most students' final C-maps maintained a similar network structure, with several maps retaining complex connections between concepts.

**Explanation results.**

Students in both classes decreased their construction of teleological explanations during the study. On the two tasks in the second week, the ECO+E class constructed teleological explanations for 6/12 or 50% of the tasks with 2/12 (16%) proximate and 3/12 (25%) evolutionary explanations. In the fourth week, this class provided 4/12 or 33% teleological explanations with 3/12 (25%) proximate and 5/12 (42%) evolutionary explanations in similar tasks. In the ECO class, students constructed 4/12 (33%) teleological explanations with 7/12 (58%) proximate and 0/12 (0%) evolutionary explanations for tasks in the second week. Similar to the ECO+E class, one student gave a simple description for Task 1 in the second week. In the fourth week, 4/12 (33%) of the students in the ECO class gave teleological explanations with 6/12 (50%) proximate and 2/12 (16%) evolutionary explanations. Table 28 summarizes the results for both classes and tasks.
Table 28

*Class Summary of Explanations*

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Teleological</th>
<th>Proximate</th>
<th>Evolutionary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 2</td>
<td>C(n=6)</td>
<td>1</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Tasks 1&amp;3</td>
<td>E(n=6)</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Week 4</td>
<td>C(n=6)</td>
<td>-</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Tasks 2&amp;4</td>
<td>E(n=6)</td>
<td>-</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: (C)=ECO/control; (E)=ECO+E/experimental.

Three main synthetic or alternate conceptions were identified from students' propositions in the three concept mapping tests, explanations for the four tasks, and pre- and post-argument reflections in both classes. These conceptions were: (a) heredity as matter passed from generation to generation, (b) genetic variations as things, and (c) changing environments causing needed mutations.

**Epistemology and motivation survey results.**

Results from the SEB survey were similar between the two classes in all four epistemological dimensions. Students in the ECO class had mean differences between pre- and posttest scores that ranged from -0.13 to 0.27 with posttest scores ranging from 3.90 (78%) in *Source* to 4.55 (91%) in *Development* dimensions. Student scores in the ECO+E class on the posttest ranged from 4.00 (80%) in *Source* to 4.41 (88%) in *Development* dimensions with mean differences that ranged from -0.24 to 0.23. SMQI survey results show similarities in scores for both classes in all five components of motivation. Student in the ECO+E class had component posttest scores that range from 3.66 (73%) in *Self-Determination* to 4.41 (88%) in *Grade Motivation* with difference in
mean ranging from -0.13 to 0.23. Student scores in the ECO class had component posttest scores that ranged from 2.86 (57%) in Self-Determination to 3.66 (73%) in Grade Motivation with a difference in mean from pre- to posttest ranging from -0.37 to 0.26.

Reflection results.

Students in the ECO+E class had a mean score of 8 for 11 reflections questions (73%) probing for science beliefs development, while the ECO class mean score was 6.7 on the same reflection questions. Mean scores on science motivation for the ECO+E class was 5.5 for 7 questions (78%) measuring self-and career/grade motivations. Students in the ECO class had similar scores with a mean of 5 (71%) for identical questions. In the ECO+E class, students (6/6=100%) scored high in science beliefs with a minimum of 7/11(64%) and 5/7(71%) in science motivations. In the ECO class, 3/6 (50%) students scored comparably in science beliefs and science motivations. Two students from this class, Chris and Don, showed lower development of science beliefs than other participants. Table 29 shows a summary of the study results obtained from student reflections for both classes.
Table 29

<table>
<thead>
<tr>
<th>Student</th>
<th>Beliefs</th>
<th>Motivations</th>
<th>Student</th>
<th>Beliefs</th>
<th>Motivations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=11</td>
<td>n=7</td>
<td></td>
<td>n=11</td>
<td>n=7</td>
</tr>
<tr>
<td>Andrew (E)</td>
<td>9</td>
<td>5</td>
<td>Chris (C)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Ann (E)</td>
<td>7</td>
<td>5</td>
<td>Don (C)</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Bill (E)</td>
<td>8</td>
<td>6</td>
<td>Kevin (C)</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Brea (E)</td>
<td>9</td>
<td>6</td>
<td>Lisa (C)</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Paige (E)</td>
<td>8</td>
<td>5</td>
<td>Mike (C)</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Zena (E)</td>
<td>7</td>
<td>7</td>
<td>Stuart (C)</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

Class Mean 8 (73%) 5.5 (78%) 6.7 (61%) 5 (71%)

Notes: C= ECO/control group; E= ECO+E/experimental group; High score=1; Low score=0; n= total possible high scores.

This chapter presented four types of student datasets produced from this study.

Data from surveys, explanations from task scenarios, pre- and post- argument reflections, and concept maps provide rich descriptive information for analysis from a multidimensional framework.
Chapter 5: Interpretations, Conclusions, and Recommendations

Learning about and understanding evolution can be problematic, despite its significance within the discipline of biology and importance in development of scientific literacy. There are many problems associated with the teaching and learning of evolution in schools. This study centered on one facet of a complex problem. Many students may come to class with alternative or scientifically inaccurate conceptions and less than receptive motivations. Consequently, teaching evolution in 'small chunks', as a learning progression, with emphasis on the development of scientific beliefs throughout the year may be a viable alternative to the more traditional curriculum. There is no literature that has explored the influences of this pedagogy, though it has been suggested as a means of organizational framework for biology (Alles, 2001; Alters & Nelson, 2002; Flammer, 2006; Hillis 2007; Padian, 2008).

The purpose this study was to explore student changes in conceptual development, epistemology, and motivations when evolution concepts are embedded and explicit reflective discourse is used within a population ecology unit. Student's conceptual development, as well as science epistemologies and motivations were assessed using validated quantitative surveys are student written artifacts were gathered. Qualitative data were analyzed from an ontological, epistemological, and motivational perspective in two classes of tenth-grade (ECO and ECO+E), general biology students.

This final chapter begins by answering the two research questions with broad generalized research claims. This chapter proceeds to build an argument by interpreting the observed changes in students' conceptual development, beliefs, and motivations.
Student learning or conceptual change is explained from a multidimensional perspective to better understand changes in student's conceptual development. This is followed by interpretations of observed changes in science beliefs and motivation during this study. Conclusions and inferences are drawn from an amalgamation of results and extant literature to support research claims from a constructivist perspective using the framework of this study's pedagogical model (Figure 1). The concluding section of this chapter and this dissertation makes implications for teaching and learning by recommending future research.

Research Question 1

What are the observed changes in student's conceptual development, epistemology, and motivation when evolution concepts are embedded and explicit reflective discourse is used in a unit for population ecology?

Students in the ECO+E class showed greater increases in conceptual understanding of evolution and higher levels of motivation as a result of perspicuous attention to alternate conceptions through reflective discourse focused on specific intervention questions. Students' science epistemology remained relatively stable throughout the study in both classes.

Research Question 2

In what ways does explicit reflection influence students' mental models when evolution is embedded within a population ecology unit?

Students in the ECO+E class showed greater levels of beliefs revision and mental model transformation than students in the ECO class. Students in the ECO+E class
increased the numbers of evolutionary explanations to tasks and construction of evolutionary propositions over the course of the study.

**Results Interpretation**

**Conceptual change in evolution.**

Over the course of the study, students in both groups (ECO and ECO+E) improved their understanding of the evolutionary ideas, as well as met the standards for ecology. Students' Conceptual Inventory of Natural Selection (CINS) surveys, declarative propositions, explanations to task scenarios, and pre-and post-argument reflection responses are quantitative and qualitative artifacts gathered in this mixed-methods study that support of this claim.

Student CINS scores increased in both classes from pre- to posttest at the end of instructional unit. The ECO+E class showed higher scores from pre- to posttest scores with a mean difference of 4.67 (ECO= 3.84) or nearly five questions. Both groups mean scores were between 11.3 (57%) and 11.5 (58%) on the CINS posttest. In the research of Nehm and Schonfeld (2008), second-semester, biology majors scored an average of 62.9% on the same survey. Student CINS scores seem extremely reasonable, particularly since students have not had any explicit, formal immersion in evolutionary theory and mechanisms of natural selection.

Analysis of student constructed propositions for concept maps indicate the ECO+E class had increased numbers of constructed evolutionary propositions and quality of their propositions from the pretest to the final test. These propositions can be used as a measure of conceptual development, since propositions are considered declarative,
conceptual, factual knowledge (Novak, 2002; Shavelson, Ruiz-Primo, & Wiley, 2005). Propositions designated as 'evolutionary' were scientific and were linked to ecological conceptions with components of natural selection (exponential growth, populations at carrying capacity, limited resources, differential survival, variations, and inheritance). Students in the ECO+E class showed consistent increases in the proportion of evolutionary propositions from pre-, post-, and final concept mapping tests.

The quality of student propositions in the ECO+E class improved from 1.7 (1.7/3=57%) in the pretest to 2.3 (2.3/3=77%) in the final test. This shows an important increase in student accuracy of declarative knowledge. Students were constructing propositions with fewer synthetic propositions. Students in the ECO group created greater numbers of propositions in each of the three concept maps, however, their overall proposition quality did not improve over the study. Proposition development seen in the ECO+E class also corresponds with the progression observed in students' evolutionary explanations throughout the study.

Student explanations in both groups progressed from descriptions and teleological orientations to proximate and evolutionary explanations when given the four task scenarios. Students in the ECO+E class constructed greater numbers of evolutionary explanations with fewer numbers of teleological explanations over the course of the study. One student explained all four tasks using evolutionary causality. His responses to tasks prompts suggested his conceptual framework for basic components of natural selection was strong, coherent, and committed. Conversely, two students' (1 per group) explanations for all four tasks showed coherence, commitment and strength in
teleological conceptions. Kampourakis and Zogza (2008, 2009) concluded from their studies a possible explanation for teleological explanations for Tasks 2 and 4 may be the lack of additional information in the task scenarios compared to Tasks 1 and 3.

Student responses to pre- and post-argument reflection questions revealed more direct-process ontology. Focus questions for investigation during inquiries formed the basis for student arguments and reflection questions before and after class argumentation served as intervention in the ECO+E class (See student Appendix C1).

**Conceptual changes in ecology.**

Both classes increased conceptual development in ecological conceptions during this instructional period. This was expected. Time spent in class on explicit discourse was only about 7.5% in the ECO+E class, and there was no direct instruction of natural selection components in the ECO class. However, students in the ECO+E seemed to be focused more on answering the reflective, intervention questions and gave more pre- and post-argument responses that virtually ignored the initial focus reflective question with a sole ecological focus. Perhaps given two questions or tasks at one time together, students concentrated on answering the last intervention question and felt pressed on time.

Regardless, student formative assessment scores were comparable with group mean scores of 69% for both assessments. Students in both groups constructed more scientific propositions than synthetic conceptions over the instructional unit, with students in the ECO+E class showing greater gains from 45% to 57%. Both classes exhibited evidence of learning evolutionary content concurrently with an overall focus on ecological content.
What accounts for the dramatic changes in evolutionary conceptions in the ECO+E class over the four-week study period reported in the previous chapter and summarized earlier? This class would not be expected to perform at this level of achievement considering the lower GPA levels and special needs of this class. Two factors may account for the overall increases in conceptual understanding in the ECO+E class. The first factor influencing this change may be the reflective discourse intervention and the second factor is the initial and somewhat stable higher motivation levels. The effects of explicit reflective discourse will now be discussed.

The Effects of Explicit Reflective Discourse

Explicit reflective discourse in the ECO+E group provided brief opportunities (7.5% total class time) to create two important conditions for conceptual change and learning. From a pragmatic constructivist perspective, the Cognitive Reconstruction of Knowledge Model (Dole & Sinatra, 1998; Sinatra, 2005) inherent within the pedagogical model of this study provided guidelines for planning instructional opportunities for both the cognitive and social construction of knowledge.

Key intervention questions supplied the catalyst for exposing alternate conceptions. Class and small group reflective discourse focused on specific intervention questions. These questions were designed to solicit alternate conceptions to stimulate dissatisfaction or cognitive dissonance during discussions. This is an important catalyst for conceptual from a cognitive constructivist perspective (Posner, Strike, Hewson, & Gertzog, 1982). Becoming aware of the inadequacies in current existing conceptions provides the cognitive motivation for conceptual change. However, as Pintrich, Marx,
and Boyle (1993) asserted, cognitive dissonance is not the only construct influencing conceptual change.

Giving perspicuous attention to these conceptions through small group and whole class discussions created contextual verbalization and interactions for the social construction of knowledge (Driver, Leach, Millar, & Scott, 1996; Scott, Asoko, & Leach, 2007; Vygotsky, 1978). Discourse opportunities with pre-planned cooperative groups provided optimal zones of proximal development and opportunities to learn through verbal participation within a social context (Sfard, 1998; Vygotsky, 1978).

However, time spent on reflective discourse intervention was minimal. How efficient was this task? Can this pedagogy account for the increases in conceptual development seen in the ECO+E group? Short class times demand efficiency in management and student awareness of and training in scientific argumentation. Students in the ECO+E class have developed experiences with argumentation procedures and concentrated on the additional one or two focus or reflective questions while still in small, assigned or negotiated groups. Answers to intervention question were brainstormed and recorded within their small groups first, and responses were recognized during brief, whole class discussions.

Five to ten minutes does not seem like much time for creating cognitive dissonance and metacognitive awareness of alternate conceptions, or social participation necessary for the construction of knowledge, but it is nearly one-quarter of the allotted class time. Students' maintained their focus on the intervention discourse because of the quick, variety of activities within each class period. Students learn early in the year that
they are expected to be on task and prepared for multiple activities within the duration of a single period. It would have been pedagogically desirable to spend more time on this task. This difference between classes was all this teacher/researcher could ethically and professionally tolerate.

Several students in the ECO+E group (Andrew and Brea) did not show transformation or revision in their teleological explanations or much improvement on the CINS pre- to posttest. Perhaps more time on intervention with reflective discourse would have created the awareness of the inaccuracies of their own existing goal and intentional conceptions would create cognitive dissonance. This reinforces the need for evolution learning progressions throughout the year. Embedding appropriate evolution activities within topics outside formal chapters would give opportunities for the conceptual negotiation or restructuring of conceptions.

If the amount of time spent in reflective discourse did not provide adequate impetus for intentional conceptual change through cognitive dissonance or social participation, then higher levels of motivational development and classroom pedagogy supporting the constructs inherent in the CRKM could account for the increase in conceptual development in this class. This next section reviews this pedagogy from an epistemological and motivational perspective.

**Epistemological and motivational changes.**

Post-argument reflection responses revealed students' epistemological commitments regarding the task message and motivational conceptions. Students found the task message to be intelligible or comprehensible and plausible (Treagust & Duit,
2008; Tyson, Venville, Harrison, & Treagust, 1997). Research results support the influence personal epistemological beliefs have on information processing, comprehension, and other determinates of engagement in challenging tasks like argumentation (Driver, Leach, Millar, & Scott, 1996; Kuhn, 1991; Schommer, 1990, 1993). Student responses indicated they found task experiences and task evidence plausible and fruitful in the construction of their argument. (Dole & Sinatra, 1998; Sinatra, 2005). Epistemological beliefs influence engagement in task and are important constructs promoting intentional conceptual change (Sinatra & Pintrich, 3003; Southerland & Sinatra, 2003).

Overall, students in the ECO+E class maintained higher levels of epistemological and motivational commitments in the two activities where responses were gathered. Students found these key tasks coherent and motivational. Many responses expressed enjoyment with the activities and liked searching and learning on their own. Most indicated the experiences were indeed more interesting because they had more control over their learning. Additionally most exhibited higher self-efficacy motivations about the tasks and arguments. This is indicative of higher levels of self-efficacy (Glynn & Koballa, 2006: Linnenbrink & Pintrich, 2003).

Some students, particularly in the ECO+E class admitted finding the autonomous situation difficult at first, but persisted and felt they were successful. Reflection responses revealed each student's self-determination in dealing with the autonomy given to them in the *The Galápagos Finches*© (bguile.northwestern.edu) and *Bug Hunt Camouflage*© (Novak & Wilensky, 2006; Wilensky, 1999) activities. This is suggestive of higher
levels of self-determination, because they displayed persistence and capability to regulate their emotions to reach a goal (Deci & Ryan, 2000; Deci, Ryan, & Williams, 1996; Dweck, 2000; Limón & Carretero, 1997, Pintrich, 2003). The social context in class argumentation seemed important in catalyzing and maintaining student engagement through the use of cooperative dyads throughout the entire key intervention. Many reflective responses implied high social context and social construction of knowledge with references to 'we', like 'we found', 'we used'.

In terms of showing epistemological differences between the ECO+E and ECO class, SEB results and student reflection responses were descriptively inconclusive. Survey scores were similar and average scores for all four dimensions were greater than 4/5 (80%). Epistemological conceptions about the task together with motivational constructs of the students may have promoted intentional conceptual changes in the ECO class, because students increased in conceptual development without explicit reflective discourse. Therefore, it can be interpreted that students were perceptive to the task message from an epistemological perspective. From a motivational perspective, context may have been a catalyst for deep engagement in the key intervention activities.

Students in the ECO+E class scored higher in all components of the SMQII in both pre- and posttests. Initial career motivation pretest mean differences were nearly 30% (4.16/5) higher in this class compared to the ECO class (2.9/5). The overall patterns of self-motivational development from the written reflection responses mirrored this motivational level. The ECO+E participants indicated strong degrees of personal relevance and intrinsic motivations in their reflection responses. High levels of intrinsic
motivation and personal relevance may have provided the incentive for deeper engagement in key activities and attentions in reflective discourse (Deci & Ryan, 2000; Deci, Ryan, & Williams, 1996; Dweck, 2000; Limón & Carretero, 1997).

**Student Mental Models**

Ascertaining student mental models requires interpretation of changes in conceptions from a more theoretic approach. Student mental models are mental representations of conceptions thought to be activated during problem solving situations (Vosniadou & Ioannides, 1998). Underpinned synthetic beliefs can be revealed in constructed explanations to tasks. The choosing of relationships between concepts in proposition construction, proposition quality, and scientific accuracy of claims exposed students' ontological status, conceptual understanding, alternate conceptions, and synthetic mental models.

Key activities, particularly those requiring the building of arguments, would be expected to promote changes in existing conceptual framework (Dole & Sinatra, 1998; Sinatra & Pintrich, 2003). Inquiry and argumentation may equivalent to the use of higher knowledge forms like schematic, and strategic knowledge (Novak, 2002; Shavelson, Ruiz-Primo, & Wiley, 2005; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). Concept maps, together with the data interpretations from additional student artifacts assessed conceptual development. This gives a glimpse into student mental models for the population ecology unit.

Propositions collectively represent students' spontaneously generated specific theories or beliefs about the connections between concepts (Vosniadou, 1994, 2007;
Vosniadou & Innannides, 1998). Perhaps perspicuous attention to alternate conceptions during intervention gave students in the ECO+E class more conceptual 'tools' through beliefs revision and connections to topical and evolutionary concepts. Even limited social negotiation with concepts may provide scaffolding or 'lifting' of presuppositions to more sophisticated models (Vosniadou, Vamvakoussi, & Skopeliti, 2008). In addition, student propositions, because they are spontaneously constructed, reveal a student's development of schematic and strategic knowledge (Shavelson, Ruiz-Primo, & Wiley, 2005). Results suggest that students in the ECO+E class may have given more consideration or care when constructing their propositions to ensure that they were scientific, or made more scientific conceptual connections between population concepts and evolutionary concepts as a result of intervention.

All student explanations seemed to exhibit direct-process ontological beliefs. However, within the confines of written data, several students have properties of emergent-process ontology. This analysis requires more in-depth explanation and discussion with participants to fully uncover ontological status. Or could this be interpreted as a partial correction of a flawed mental model? Careful attention to the dynamic nature of conceptual development with increased study duration may help illuminate this negotiation process.

**Inconclusive Interpretations**

Overall, student results on the H-map were mixed. Measuring conceptual changes with these artifacts was inconclusive. The quality of propositions was lower for the ECO class and remained the same for the ECO+E class. Several factors contributed to
this situation. First, because of the numbers of concepts, students exhibited fatigue and disinterest when making similarity judgments. Despite the fact this task was divided over two class periods, students became bored, disinterested, and needed encouragement to finish. Another factor contributing to the inconclusiveness of this data set was the complexity of structure in the cognitive-associative maps given back to the students. Numerous additional linkages were added to most maps, when compared to the pre- and final C-maps. When given these maps students felt compelled to leave all linkages and complained softly during map reconstruction about not understanding the connections between the concepts. This led to hasty construction of propositions in both classes. Most students were anxious and distressed over the task.

As a 'window into the mind' (Shavelson, Ruiz-Primo, & Wiley, 2005), to be used as a mental model the numbers of concepts must be reduced to avoid the two factors just described. These factors are due to the novel study design not to the tools or constructs. Regardless, it was a learning experience for all, but did not add much data. Luckily, study methodology stipulated a final, 6-week final test. These two factors should be considered, especially for younger students.

**Conclusions**

This study's conceptual framework elaborates on the importance of interpreting student conceptions from three dimensions. Conclusions must consider all of these constructs. This requires inferences about student changes from the perspective of conceptual frameworks that include ontological, epistemological, and motivational conceptions. Constructing rational inferences concerning students' mental models
requires understanding conceptions relating ontological and epistemological beliefs. From a multidimensional perspective, personal epistemologies and motivational conceptions must be amalgamated into this reasoning.

What was learned about student conceptual changes with judicious certainty from this study? This study design does not allow for drawing any statistical or causal inferences about the effectiveness of the curriculum or pedagogy. However, this study does permit a description of the observable changes and students' experiences and learning during this study.

First assertion.

Students in both classes developed ecological and evolution conceptions during this study. However, students in the ECO+E class showed greater increases in conceptual understanding of evolution and higher levels of motivation as a result of perspicuous attention to alternate conceptions through reflective discourse focused on specific intervention questions. Students' science epistemologies remained relatively stable throughout the study in both classes.

Both classes experienced beliefs revision in evolution was demonstrated, with model transformation in students (Chi, 2008). Evolutionary beliefs became restructured into student conceptual frameworks and were generated with certain degrees of coherency in intervention tasks. Some students consistently revealed coherency in conceptual frameworks, like Bill with his evolutionary explanations or Andrew and Stuart with their consistent teleological explanations and responses. Several ontological
and epistemological beliefs may have been tentatively given inaccurate status, due to the short instructional unit and limitations of written artifacts and surveys.

Overall, students showed 'negotiation' between belief commitments. Students' propositions, responses, and explanations showed mixtures of synthetic conceptions and scientific conceptions throughout the study. This is not unexpected, since students have had little experience with the concepts inherent in the embedded activities. The purpose of embedding was to provide opportunities for 'negotiation' with concepts so students construct and revise beliefs, with the goal of developing scientifically accurate, cohesive conceptual frameworks in biology. Students in the ECO+E class received explicit intervention that gave perspicuous attention to alternate conceptions through reflective discourse. Students in the ECO class learned implicitly or vicariously through the embedded evolutionary activities within this study unit. This leads to the second logical assertion.

**Second assertion.**

It is reasonable to deduce that students, particularly in the ECO class, were receptive to the task's message and developed an understanding of the concepts inherent in these key task activities. Students improved in their conceptual understanding over this unit. Embedded negotiations and experiences with evolution and attending to student motivations other than cognitive dissonance may have stimulated intentional conceptual change in the ECO class. Key activity tasks were perceived as comprehensible, coherent, intelligible, and plausible, along with motivational commitments that catalyzed high degrees of engagement and commitment (Dole & Sinatra, 1998; Sinatra, 2005; Treagust
and Duit, 2008; Tyson, Venville, Harrison, & Treagust, 1997). These activities provided optimal contexts for participation and the social construction of knowledge, through argumentation and problem-based inquiry (Driver, Leach, Millar, & Scott, 1996; Scott, Asoko, & Leach, 2007; Sfard, 1998; Vygotsky, 1978). Key intervention activities supported the cognitive construction of knowledge. Minimal class time was given to explicit reflective discourse in the ECO+E class. Time was not devoted to formal instruction relating to components of natural selection in the ECO class (Mayr, 1988). Yet these students learned implicitly concepts of natural selection inherent in the activities. Pedagogy must have driven this conceptual change.

According to the Cognitive Reconstruction of Knowledge Model (CRKM) that underpins the model of pedagogy (Figure 1) used in this study, key interactions create a classroom learning context conducive to conceptual change by considering both the learner conceptions and the task message for an optimal student engagement (Dole & Sinatra, 1998; Sinatra, 2005). So embedding these key evolution activities as task messages, together with consideration to learner characteristics, helped to bring about intentional conceptual change within this instructional unit (Limón Luque, 2003; Sinatra and Pintrich, 2003; Southerland and Sinatra, 2003).

By attending to the context of instruction and maximizing student engagement, students may have been more intrinsically inclined to seek answers and engage in their own learning. Students in the ECO class increased their conceptual understanding of evolution without any perspicuous attention given to evolution concepts. Correspondingly, students in the ECO+E had lower academic achievement (GPA
average). Yet this group demonstrated higher levels of evolutionary understanding with comparable epistemological and motivational conceptions.

Another point must be made. Since concepts within the key activities required applications of natural selection and 'thinking outside the box' of a typical population ecology unit, students may have sought out discussions and homework ideas with other students (see researcher notes in Chapter 4, p. 125) or learned concepts independently. Several student artifacts referred to conceptions outside the realm of intervention, like 'evolution' or 'evolved' and 'natural selection' scientifically within responses and explanations. Students displayed characteristics of intrinsic motivation and self-determination in this study.

**Tentative Conclusions**

It can be tentatively conjectured or extrapolated that embedding evolution throughout the curriculum as 'small chunks' may cognitively scaffold a way to important evolutionary connections. This tentative conclusion is supported by observed changes in students' conceptual development and with extant literature. Providing opportunities for the experiences and negotiations with less familiar concepts can stimulate the development of more scientific or sophisticated mental models (Chi, 2008; Vosniadou, Vamvakoussi, & Skopeliti, 2008). Encountering and engaging in mental negotiations with the concepts throughout the year may contribute to adding beliefs and making revisions that 'lift' more synthetic presuppositions (Vosniadou, Vamvakoussi, & Skopeliti, 2008) or initiate category shifts (Chi, 2008).
Research supports the assertion that synthetic, alternative conceptions in evolution have been traditionally, deeply entrenched from earlier years and remain unchanged through high school and beyond (Bishop & Anderson, 1990; Brumby, 1984; Evans, 2008; Southerland, Abrams, Cummins, and Anzelmo, 2001). There were several opportunities within this study to address perspicuously and give additional attention to synthetic conceptions if it were not for stringent controls of the study boundaries and time constraints. Perhaps, more negotiation and reflection with synthetic conceptions, or p-prims, would provide catalyst to be transformational or promote category shifts (Chi, 2008). Could p-prims be viewed as student negotiations with beliefs and presuppositions from this perspective?

In this study, pre- and post-argument reflection responses in the Bug Hunt Camouflage© (Novak & Wilensky, 2006 Wilensky, 1999), were in response to the general investigative question, 'How do environmental factors influence a bug population over time?' Students in the ECO class up until this time had given reflection responses with ecological orientations (see Appendix C1 for all student responses). This investigative question is evolutionary in orientation, because it probes for changes in populations over time. The 'over time' shifted students' prior emphases on ecology toward evolutionary explanations. Students in this class began using teleological conceptions in their reflection responses, though their arguments were still focused on justifying their claims with model evidence. So one might argue these teleological responses for explanations observed in this study, were student attempts to fill huge 'gaps'
in anatomical and physiological causation for adaptations. Perhaps students resort to simpler, less exhausting, explanations using teleology?

This opens up the old questions regarding teleological explanations offered by Mayr (1988) over three decades ago and more recently by additional science education researchers (Sinatra, Brem, & Evans, 2008; Sinatra, Southerland, Mcconaughy, & Demastes, 2003; Southerland, Abrams, Cummins, & Anselmo, 2001; Zohar & Ginossar, 1998). Mayr (1988) discussed biologists' uses of teleology to simplify explanations and shorten explanations for convenience of discussion. Do students use teleological explanations, because this is the media messages heard from scientists or a time saving response? This remains to be studied further.

**Implications for Teaching and Learning**

There are several broad implications for teaching and learning that can be drawn from this study, in addition to the specific H-maps recommendations previously discussed. These suggestions and effects can be organized into three areas. Implications involve: 1) continued study of an embedded curriculum, 2) investigations and concerns related to alternate conceptions, and; 3) continued study into naïve conceptions of the NOS and the development of science beliefs.

The first suggestion is to examine the effects of embedding evolution in other areas within the curriculum. A longitudinal study could examine students' conceptual frameworks in biology over a progression of time. This involves a commitment to unobtrusive investigation into students' mental models in action as a dynamic process. This may involve monitoring changes in acceptance and other affective components over
time for interpretation of change from a multidimensional perspective. Another implication for the teaching and learning of biology is to explore actively specific instructional strategies for teaching systems that demand continued engagement in emergent processes. In this way students would be negotiating presuppositions that prevent students from developing scientifically accurate models of evolution.

This leads into the second area for recommendations for further study and cautions. This study revealed the development of synthetic, alternative conceptions surrounding the concept of environment and variations. As knowledge and innovations generated from evolutionary biology studies trickle down and become incorporated into the curricula for younger students, it has added another dimension of complexity and hierarchy with conceptions in molecular biology. The discoveries of the hierarchical nature over the control of structural genes, along with the vast amounts of information relating to epigenetic controls over expression, necessitates a cautious concern about the use of common conceptions like the 'environment'. Influences on structural gene expression are no longer solely considered to be resultant from random mutation or mutagenesis, rather it has become much more complex over the years. This study has illuminated how conceptions like epigenetic control and gene switches at the molecular level can be amalgamated into synthetic conceptions involving larger systems at the ecosystem level.

The final area for further study, considers further exploration of student changes in naïve conceptions of the NOS. As described and inferred while situating this study, students do not learn in a vacuum. Cultural and contextual factors exert an enormous
influence over learning. Students with novice experiences and naïve conceptions can successfully defend and build scientific arguments. Suggestions for further study include investigating changes in science beliefs and specifically examining students' mental models in the NOS. This necessitates interpretation from a multidimensional perspective. Personal epistemologies, metacognition, religious beliefs, together with motivations would give a picture of the epistemological framework for the NOS, and would add to the existing body of literature.
References


National Academy of Sciences. NAS. (1998). Teaching about evolution and the nature of science. Washington, D.C. Available at:

http://www.nap.edu/openbook.php?record_id=5787


http://www.nap.edu/catalog.php?record_id=13165


doi:10.1002/tea.20251


[http://ccl.northwestern.edu/netlogo/models/BugHuntCamouflage](http://ccl.northwestern.edu/netlogo/models/BugHuntCamouflage), Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.


*Learning and Instruction, 4*, 45-69.


Appendix A: Approval and Consent Forms

Appendix A1: IRB Approval

The following research study has been approved by the Institutional Review Board at Ohio University for the period listed below. This review was conducted through an expedited review procedure as defined in the federal regulations as Category(ies): 7

Project Title: Explicitly Imbedding Evolution: Exploring Stuent Conceptual Change, Epistemology, and Science Motivation

Primary Investigator: Nancy L. Rosea
Co-Investigator(s):

Faculty Advisor: Ralph Martin
Department: Science Education

Rebecca Cale, AAB, QIP
Office of Research Compliance

Approval Date 02/07/12
Expiration Date 02/06/13
Appendix A2: District and School Approval

School District
High School
Consent Form

The City School District and High School grant permission for Nancy Rose, science teacher, to participate in educational research with her students in two Biology I classes for second semester, ecology unit on populations in the 2011-2012 school year.

District and high-school administration understand that this research is a requirement for finishing PhD studies at Ohio University in science education.

It is also understood that all principles and guidelines mandated in the National Research Act (Pub. L 93-348) for scientific research on human subjects in an education classroom will be adhered to. These measures include gaining informed consent from parents for their student. This informed consent gives the purpose of the research, length of study, risks and benefits, and confidentiality measures.

While every effort will be made to keep students' study-related information confidential, we understand that there may be circumstances where this information must be shared with:

* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

________________, District Superintendent

_________________________________ Date ______________________

________________, Principal

_________________________________ Date ______________________
Appendix A3: Parental Consent Form

Title of Research: Student Knowledge, Science Beliefs, and Motivation in an Ecology Unit
Researcher: Nancy Rose

I am asking permission for your child to participate in research. This research is a requirement for finishing my studies at Ohio University in science education.

For you to be able to decide whether you want your child to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your child’s personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your child’s participation in this study.

**Explanation of Study**

Your child is a student in one of my two Biology I classes that were selected for this study. The purpose of this research is to investigate student changes in knowledge, science beliefs, and motivations when selected topics of natural selection are included within an ecology unit. All concepts covered during this study are included in the state standards for life science. For all practical purposes, your child will not observe any changes in classroom instruction and the unit will be challenging. Classes include normal activities like, laboratories and group work. However, in order to do a scientific study, specific forms of information must be gathered and analyzed.

Your child will be asked to complete several surveys before and after this ecology unit. These surveys are designed to monitor changes in knowledge and motivations as a result of his/her study in this ecology unit. Written answers to selected questions, explanations, and concept maps that are a familiar part of your child’s normal assessment may become part of the information used in this study, as well.

Participation is voluntary. Your child may leave the study at any time and their written information will not become part of my study, but may still be used as part of a typical assessment for his/her biology grade. If you or your child decides to stop participation in this study, there will be no penalty for your child.

This study will last approximately six to seven weeks.

**Risks and Discomforts**

No risks or discomforts are anticipated.

**Benefits**

This study will provide measurable student outcomes that can be used to guide future curricular decisions and will contribute to generalizable knowledge in science education. Grades will not be influenced by participation in this study.

**Confidentiality and Records**

Efforts will be made to keep your child’s study-related information confidential. Your child’s study information will be kept confidential by using no identifying names or initials. Additionally, while every effort will be made to keep your child’s study-related information confidential, there may be circumstances where this information must be shared with:

- Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
- Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

**Contact Information**

If you have any questions regarding this study, please contact me, Nancy Rose, or my advisor, Dr. Ralph Martin, PhD., martin@ohio.edu.

If you have any questions regarding your child’s rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks to your child and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries your child might receive as a result of participating in this study
- you are 18 years of age or older
- your child’s participation in this research is completely voluntary
- your child may leave the study at any time. If your child decides to stop participating in the study, there will be no penalty to your child and he/she will not lose any benefits to which he/she is otherwise entitled.
Appendix A4: Participant Consent Form

Title of Research: Student Knowledge, Science Beliefs, and Motivation in an Ecology Unit

Researcher: Nancy Rose

I am asking permission for you to participate in research. This research is a requirement for finishing my studies at Ohio University in science education.

For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow you to participate in this study.

Explanation of Study
You are in one of my two Biology I classes that were selected for this study. The purpose of this research is to investigate changes in your knowledge, science beliefs, and motivations when selected topics of natural selection are included within an ecology unit. All concepts covered during this study are included in the state standards for life science.

For all practical purposes, you will not observe any changes in classroom instruction and the unit will be challenging. Classes include normal activities like, laboratories and group work. However, in order to do a scientific study, specific forms of information must be gathered and analyzed.

You will be asked to complete several surveys before and after this ecology unit. These surveys are designed to monitor changes in your knowledge and motivations as a result of your study in this ecology unit. Written answers to selected questions, explanations, and concept maps that are a familiar part of your normal assessment may become part of the information used in this study, as well.

Participation is voluntary. You may leave the study at any time and their written information will not become part of my study, but may still be used as part of a typical assessment for your biology grade. If you decide to stop participation in this study, there will be no penalty for you.

This study will last approximately six to seven weeks.

Risks and Discomforts
No risks or discomforts are anticipated.

Benefits
This study will provide measurable student outcomes that can be used to guide future curricular decisions and will contribute to generalizable knowledge in science education.

Grades will not be influenced by participation in this study.

Confidentiality and Records
Efforts will be made to keep your study-related information confidential. Your study information will be kept confidential by using no identifying names or initials.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

Contact Information
If you have any questions regarding this study, please contact me, Nancy Rose, or my advisor, Dr. Ralph Martin, PhD., marting@ohio.edu

If you have any questions regarding your child’s rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

Minor Permission
By signing below, you are agreeing that:

· you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions
· known risks to you have been explained to your satisfaction.
· you understand Ohio University has no policy or plan to pay for any injuries you might receive as a result of participating in this research protocol
· your participation in this research is given voluntarily
· you may change your mind and stop participation at any time without penalty or loss of any benefits to which you may otherwise be entitled.

Signature_________________________________________ Date______________

Printed Name_________________________________________ Version Date: 02/06/12
Appendix B: Assessments and Intervention

Appendix B1: Scientific Epistemological Beliefs Survey

The following statements are about your beliefs about knowledge and learning. Please indicate how strongly you agree or disagree with each of the statements listed below. Please select the number that best describes the strength of your belief. There is no right or wrong answer.

1. Everybody has to believe what scientists say.
2. In science, you have to believe what the science books say about stuff.
3. Whatever the teacher says in science class is true.
4. If you read something in a science book, you can be sure it's true.
5. Only scientists know for sure what is true in science.
6. All questions in science have one right answer.
7. The most important part of doing science is coming up with the right answer.
8. Scientists pretty much know everything about science; there is not much more to know.
9. Scientific knowledge is always true.
10. Once scientists have a result from an experiment, that is the only answer.
11. Scientists always agree about what is true in science.
12. Some ideas in science today are different than what scientists used to think.
13. The ideas in science books sometimes change.
14. There are some questions that even scientists cannot answer.
15. Ideas in science sometimes change.
16. New discoveries can change what scientists think is true.
17. Sometimes scientists change their minds about what is true in science.
18. Ideas about science experiments come from being curious and thinking about how things work.
19. In science, there can be more than one way for scientists to test their ideas.
20. One important part of science is doing experiments to come up with new ideas about how things work.
21. It is good to try experiments more than once to make sure of your findings.
22. Good ideas in science can come from anybody, not just from scientist.
23. A good way to know if something is true is to do an experiment.
24. Good answers are based on evidence from many different experiments.
25. Ideas in science can come from your own questions and experiments.
26. It is good to have an idea before you start an experiment.

All responses
O Strongly disagree   O disagree   O neutral   O agree    O Strongly agree

Instrument Source:
"Changes in epistemological beliefs in elementary science students" by A.M Conley, P. R. Pintrich, I. Vekiri, and D. Harrison, 2004, Contemporary Educational Psychology, 29, 186-204. Copyright 2004 by Elsevier, Inc.
Personal Communication

Use of your SEB Instrument

AnneMarie Conley [ampm@uci.edu]
To: Rose, Nancy L.  

Hi Rose,

I'm glad you used the survey. We included the items in an appendix for just that reason.

Good luck with your work.

AnneMarie

*****************************************************************************
AnneMarie Conley, Ph.D.
Assistant Professor
Department of Education
University of California, Irvine
3200 Education Bldg.
Irvine, CA 92697-5500
(949) 824-6796 - office
Appendix B2: Science Motivation Questionnaire II

In order to better understand what you think and how you feel about your high school science course, please respond to each of the following statements from the perspective of "When I am in a high school science course..."

1. The science I learn is relevant to my life.
2. I like to do better than other students on science tests.
3. Learning science is interesting.
4. Getting a good science grade is important to me.
5. I put enough effort into learning science.
6. I use strategies to learn science well.
7. Learning science will help me get a good job.
8. It is important that I get an "A" in science.
9. I am confident I will do well on science tests.
10. Knowing science will give me a career advantage.
11. I spend a lot of time learning science.
12. Learning science makes my life more meaningful.
13. Understanding science will benefit me in my career.
14. I am confident I will do well on science labs and projects.
15. I believe I can master science knowledge and skills.
16. I prepare well for science tests and labs.
17. I am curious about discoveries in science.
18. I believe I can earn a grade of "A" in science.
19. I enjoy learning science.
20. I think about the grade I will get in science.
21. I am sure I can understand science.
22. I study hard to learn science.
23. My career will involve science.
24. Scoring high on science tests and labs matters to me.
25. I will use science problem-solving skills in my career.

Response choices: O Never   O Rarely   O Sometimes   O Usually   O Always
Personal Communication

Shawn M Glynn [sglynn@uga.edu]

To: Rose, Nancy L

Thursday, December 01, 2011 2:31 PM

Dear Nancy,

Yes, you have permission (see below). Students’ motivation to learn science is an important and fascinating area of science-education research, with many discoveries to be made. The motivation to learn science is essential for students’ science achievement and attitudes.

The Science Motivation Questionnaire II (SMQ-II), used with qualitative techniques such as interviewing, is a valid and efficient tool for researchers and science teachers to assess students’ motivation to learn science.

This website http://www.coe.uga.edu/smq/ has the SMQII, permission directions, and all available articles, which you can download.

The website and the articles explain how the SMQ-II was designed to assess not only science motivation in general, but motivation to learn specific areas of science. For example, if the word “science” is replaced with the word “biology” in each of the SMQ-II items, then the result is the Biology Motivation Questionnaire-II (BMQ-II). There are versions of the SMQ-II for many science areas, and there will soon be translations in a variety of languages.
Appendix B3: Conceptual Inventory of Natural Selection

Please choose the answer that best reflects how a biologist would think about each question.

---

**Galapagos Finches**

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to the islands one to five million years ago (Lack, 1940). Recent research (Burns, et al, 2002) suggests that the original finches came from the Caribbean Islands. Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes as shown in this figure.

---

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

1. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived? Given enough time,
   a. the finch population would stay small because birds only have enough babies to replace themselves.
   b. the finch population would double and then stay relatively stable.
   c. the finch population would increase dramatically.
   d. the finch population would grow slowly and then level off.

2. Finches on the Galapagos Islands require food to eat and water to drink.
   a. When food and water are scarce, some birds may be unable to obtain what they need to survive.
   b. When food and water are limited, the finches will find other food sources, so there is always enough.
   c. When food and water are scarce, the finches all eat and drink less so that all birds survive.
   d. There is always plenty of food and water on the Galapagos Islands to meet the finches' needs.

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

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

5. Depending on their beak size and shape, some finches get nectar from flowers, some eat
grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?

a. Most of the finches on an island cooperate to find food and share what they find.
b. Many of the finches on an island fight with one another and the physically strongest ones win.
c. There is more than enough food to meet all the finches' needs so they don't need to compete for food.
d. Finches compete primarily with closely related finches that eat the same kinds of food, and some may die from lack of food.

6. How did the different beak types first arise in the Galapagos finches?

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

7. What type of variation in finches is passed to the offspring?

a. Any behaviors that were learned during a finch's lifetime.
b. Only characteristics that were beneficial during a finch's lifetime.
c. All characteristics that were genetically determined.
d. Any characteristics that were positively influenced by the environment during a finch's lifetime.

8. What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?

a. The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
b. All finches are essentially alike and there are not really fourteen different species.
c. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.
d. Different lines of finches developed different beak types because they needed them in order to obtain the available food.

**Venezuelan Guppies**

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

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

10 Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the "most fit"?
   a. large body size and ability to swim quickly away from predators
   b. excellent ability to compete for food
   c. high number of offspring that survived to reproductive age
   d. high number of matings with many different females.

11 Assuming ideal conditions with abundant food and space and no predators, what would happen if a mating pair of guppies was placed in a large pond?
   a. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to replenish the population.
   b. The guppy population would grow slowly at first, then would grow rapidly, and thousands of guppies would fill the pond.
   c. The guppy population would never become very large, because only organisms such as insects and bacteria reproduce in that manner.
   d. The guppy population would continue to grow slowly over time.

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

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

Canary Island Lizards

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent (Thorpe & Brown, 1989). Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.
Choose the one answer that best reflects how an evolutionary biologist would answer.
14 Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?
   a Finding food is not a problem since food is always in abundant supply.
   b Since lizards can eat a variety of foods, there is likely to be enough food for all of the lizards at all times.
   c Lizards can get by on very little food, so the food supply does not matter.
   d It is likely that sometimes there is enough food, but at other times there is not enough food for all of the lizards.

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

16 A well-established population of lizards is made up of hundreds of individual lizards. On an island, all lizards in a lizard population are likely to...
   a. be indistinguishable, since there is a lot of interbreeding in isolated populations.
   b. be the same on the inside but display differences in their external features.
   c. be similar, yet have some significant differences in their internal and external features.
   d. be the same on the outside but display differences in their internal features.

17. Which statement best describes how traits in lizards will be inherited by offspring?
   a. When parent lizards learn to catch particular insects, their offspring can inherit their specific insect-catching-skills.
   b. When parent lizards develop stronger claws through repeated use in catching prey, their offspring can inherit their stronger-claw trait.
   c. When parent lizards’ claws are underdeveloped because easy food sources are available, their offspring can inherit their weakened claws.
   d. When a parent lizard is born with an extra finger on its claws, its offspring can inherit six-fingered claws.

18. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional female lizards. Which lizard might a biologist consider to be the "most fit"?

<table>
<thead>
<tr>
<th></th>
<th>Lizard A</th>
<th>Lizard B</th>
<th>Lizard C</th>
<th>Lizard D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body length</td>
<td>20 cm</td>
<td>12 cm</td>
<td>10 cm</td>
<td>15 cm</td>
</tr>
<tr>
<td>Offspring surviving to adulthood</td>
<td>19</td>
<td>28</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>Age at death</td>
<td>4 years</td>
<td>5 years</td>
<td>4 years</td>
<td>6 years</td>
</tr>
<tr>
<td>Comments</td>
<td>Lizard A is very healthy, strong and clever</td>
<td>Lizard B has mated with many lizards</td>
<td>Lizard C is dark-colored and very quick</td>
<td>Lizard D has the largest territory of all the lizards</td>
</tr>
</tbody>
</table>
19. According to the theory of natural selection, where did the variations in body size in the three species of lizards most likely come from?

a. The lizards needed to change in order to survive, so beneficial new traits developed.
b. The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
c. Random genetic changes and sexual recombination both created new variations.
d. The island environment caused genetic changes in the lizards.

20. What could cause one species to change into three species over time?

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

Hi Nancy,

I am glad to hear of your interest in the CINS, as well as the concept cartoons. I am on sabbatical right now, and am working on a revision of the CINS. Depending on when you plan to collect your data, I would suggest that you consider using the 2012 version for two reasons:

1. The CINS is fundamentally the same as the 2004 version in terms of the concepts being assessed and the format of the questions.

2. The new version is substantially improved in terms of both the reliability and readability of the CINS achieved by simplifying some sentences, and substituting words that some students did not know. In addition, extensive work has been done to improve the pairing of the two items on each concept. As you probably know, the CINS assesses 10 concepts with 2 items on each concept. Ideally, students should either choose both correct or both incorrect answers on both items in a pair. However, in earlier versions, this was often not the case. We have spent (and are still spending) a great deal of time interviewing students, then field testing revised items to assess the improvements. We are making great progress, and I am excited about introducing the new CINS soon. This revision process is taking place with both college non-majors and high school students.
Appendix B4: Population Quiz 2

Ecology and Populations Quiz 2

Put the correct answer after the line (in purple) in front of the question. Do not change the font and use purple color!!!

1. How does the logistic model of population growth differ from the exponential model?
   a. The exponential model shows a restricted growth rate.
   b. The logistic model considers the environment's carrying capacity.
   c. The graph of the exponential model is S shaped.
   d. The graph of the logistic model has a longer lag phase.

2. A breeding pair of rabbits escaped from their cage behind a farmer's barn. The farmer observed the rabbits and kept data on their population size for ten years. During this time, the rabbits reproduced and their offspring reproduced many times. The fenced, undisturbed two acres where the rabbits live support populations of predators, such as hawks and snakes, as well as a limited supply of grass and water. At the end of the ten years, the farmer graphed the data he collected. Which of the following best describes his graph?
   a. The graph is generally J shaped showing exponential growth.
   b. The graph is generally S shaped showing logistic growth.
   c. The graph is a horizontal line showing the effects of predation.
   d. The graph angles up in a straight line at 45° showing the effects of ample resources.

3. Which will reduce competition within a species' population?
   a. fewer individuals
   b. higher birthrate
   c. fewer resources
   d. higher population density

4. Water lilies do not grow in desert sand because water availability to these plants in a desert is
   a. a limiting factor.
   b. the carrying capacity.
   c. a competition factor.
   d. none of the above

5. A disease resulting in the deaths of one-third of a dense population of bats in a cave would be a
   a. density-dependent limiting factor.
   b. result of exponential growth.
   c. density-independent limiting factor.
   d. nutrient-limiting factor.

6. Which of the following involves a situation in which a density-dependent factor influences a population?
   a. Several seasons passed during which rainfall was ample, winters were not severe and food for snow hares was in good supply.
   b. A hurricane severely disrupted a salt marsh and uprooted most of the marsh grass in an estuary.
   c. A forest fire on the north side of a mountain forced the white-tailed deer from the north side to move into the range of the white-tailed deer on the south side of the mountain, making food more scarce.
   d. After a heavy rain, pesticides that were applied to a cotton crop to control weevils ran off into a waterway that flows next to a field.
7. American bison, which are large grazing mammals, are most often found clumped in small
groups. What might you infer about the spatial distribution of American bison?
a. A clumped group provides better protection from predators.
b. A clumped group attracts more prey.
c. A clumped group can graze a larger area.
d. A clumped group takes better advantage of water resources.

8. Matter can recycle through the biosphere because
a. matter is passed out of the body as waste.
b. matter is assembled into chemical compounds.
c. biological systems do not use up matter, they transform it.
d. biological systems use only carbon, oxygen, hydrogen, and nitrogen.

9. There are 150 Saguaro cacti plants per square kilometer in a certain area of Arizona desert. To
which population characteristic does this information refer?
a. growth rate
b. geographic distribution
c. age structure
d. population density

10. A small farming community in Texas covers 14 square kilometers. There are 420 individuals who
live within the town limits. What is the population density of this community?
a. 0.03 individuals per square kilometer
b. 53 individuals per square kilometer
c. 30 individuals per square kilometer
d. 10.24 individuals per square kilometer

11. What is happening in a population as it decreases?
a. The birthrate and the death rate remain the same.
b. The death rate becomes lower than the birthrate.
c. The death rate stays the same and the birthrate increases.
d. The death rate becomes higher than the birthrate.

12. A biotic or an abiotic resource in the environment that causes population size to decrease is a
a. carrying capacity.
b. limiting nutrient.
c. limiting factor.
d. growth factor.

13. If a population grows larger than the carrying capacity of the environment, the
a. death rate may rise.
b. birthrate may rise.
c. death rate must fall.
d. birthrate must fall.
14. If a limiting nutrient is supplied to the producer in Figure 3-5, Diagram II, what effect could it have on the birds? Explain your answer completely and make sure you use these terms: competition, limiting nutrient (or resource), differential survival, and population

A student grew a bacteria culture ‘A’ on sterilized nutrient medium in a closed dish for five days. Each day, she took the same size sample from the dish and placed it on a special slide used for counting microorganisms (see the top half of Figure 4-2). She examined the samples under a microscope and drew the illustrations of her observations over the course of the investigation. Each dot represents ten bacteria cells.

15. Which graph (A, B, or C in the bottom half of Figure 4-2) best pictures the growth of the student's bacteria A population? Explain.
16. In Figure 4-2, how could the carrying capacity of the culture dish be increased?
17. In Figure 4-2, how could you estimate the population size of the bacteria in Day 3 without counting all the dots in all the squares?
18. Predict what might happen if you placed 5 dots (50 bacteria) of another species of bacteria ‘B’ into the Day 2 culture.

Construct a paragraph explanation for the following two scenarios on populations.

19. Beetles may live on trees and feed on their leaves. Several years ago, both green and brown beetles could be found in equal proportions within a population in a forest. However, birds could spot the green beetles more easily that the brown ones on the ground or on the trunks. If we attempt to estimate the proportions of green and brown beetles within a population, we will mostly find brown ones. Can you explain how the proportions of the beetles living in the forest have changed?
20. Many animals exhibit the same color with their environment (e.g. the white polar bear) or look like different species (e.g. leaf-like insects) that distracts their predators or preys. Can you explain how these particular animals have developed these features?

Test Items and figures are adapted from Glencoe Science Biology.
Copyright by McGraw-Hill Companies, Inc.
Appendix B5: Concepts for Map

The orchid mantis below on the green leaf is visible. The orchid mantis actually lives and hunts among the orchids shown on the left.

Use the concepts below and write propositions to link concepts using this focus question to help you think about the relationships of the concepts.

Focus Question: How can the body coloring, markings, and shape of the orchid mantis populations be explained?

Concepts

<table>
<thead>
<tr>
<th>Carrying Capacity</th>
<th>Genes</th>
<th>Limiting Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing Environments</td>
<td>Genetic Variations</td>
<td>Mutations</td>
</tr>
<tr>
<td>Differential Survival</td>
<td>Heredity</td>
<td>Populations</td>
</tr>
<tr>
<td>Ecosystems</td>
<td>Individual Organisms</td>
<td>Reproduction</td>
</tr>
</tbody>
</table>

To start this task, first write out your answer (argument) to the focus question. Then try to make propositions from each sentence that you have written.

Do your best to try to use all concepts. Use the spaces below to write your propositions.
Appendix B6: Concept Similarities Task Example

Directions: Please use the complete range of numbers (1-7) to judge the relatedness of the concept pairs. If you feel that the concepts are somewhat related use (4), or if you are unsure or "Do not Know" use DK (4).

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Carrying Capacity</th>
<th>Genes</th>
<th>Limiting Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing Environments</td>
<td>Genetic Variations</td>
<td>Mutations</td>
<td></td>
</tr>
<tr>
<td>Differential Survival</td>
<td>Heredity</td>
<td>Populations</td>
<td></td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Individual Organisms</td>
<td>Reproduction</td>
<td></td>
</tr>
</tbody>
</table>

1. **Populations**
   
   Less related 2 3 4 5 6 7 More Related

2. Limiting Factors

3. Ecosystem

4. Reproduction

5. Heredity

6. Mutations

7. Populations

8. Limiting Factors

9. Populations

10. Heredity

11. Ecosystem

12. Reproduction

13. Mutations

14. Populations

15. Limiting Factors

16. Ecosystem

17. Reproduction

18. Heredity

19. Mutations

20. Populations

21. Limiting Factors

22. Ecosystem

23. Limiting Factors

24. Mutations

25. Mutations

26. Ecosystem

27. Limiting Factors

28. Mutations

29. Genetic Variations

Differential Survival
### Appendix B7: Embedded Curriculum

#### Table B6

<table>
<thead>
<tr>
<th>Grading Period</th>
<th>Topics</th>
<th>Evolution Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to Biology - Characteristics and Interrelatedness of Life with NOS</td>
<td>Classification - Tree of life, taxonomy, homologous structures, cladogram, embryology. Chemistry - molecular evidence; protein modeling, amino acid and DNA comparisons. Cells - fossil evidence, geologic time, cytochrome b - three domains.</td>
</tr>
<tr>
<td>2</td>
<td>Cells and Processes</td>
<td>Endosymbiont hypothesis, evolution of photosynthesis, cellular respiration. Protein synthesis, mutations and variations - hemoglobin; Genes, chromosomes, cell division; gene hierarchies and hox genes.</td>
</tr>
<tr>
<td>3</td>
<td>Ecology and Classic Genetics</td>
<td>Differential survival, limited resources, population changes over time. Hardy Weinberg principle; biotechnology.</td>
</tr>
<tr>
<td>4</td>
<td>Human Inheritance, Evolution, and Biodiversity</td>
<td>Geologic time revisited and macroevolution. Natural selection and Darwin; hominid evolution and culture. Human impact - extinctions and biodiversity.</td>
</tr>
</tbody>
</table>
Appendix B8: Reflection Question Analysis

*Red- Instruments; *Blue- CRKM

About Your Argument  (Task Message)
1. Is your claim "scientific"? Explain. (Source-Justification dimension) (comprehensible, coherent)
   [High]=cites multiple sources of data as evidence; may justify; application of argument
2. What evidence did you use to support your claim? (Source, Justification-dimension)
   (comprehensible, coherent)
   [High]=cites multiple sources of data; may justify
3. Did your claim change when you saw conflicts in data during your argument? (Certainty/Development-dimension) (comprehensible, coherent)(dissatisfaction)
   [High]= open to changing claim or considering other claims, realizing that there may be other positions
   (Source/Justification-dimension) (coherent, rhetorically compelling)
   [High]= gives patterns and justifies or explains the pattern
5. How is your argument similar to an argument a professional scientist would make? (Source/Justification-dimension) (M- Intrinsic motivation, self-determination) (rhetorically compelling, need for cognition)
   [High]= compares student developed scientific claim to scientists work
6. Where do you find scientific knowledge? (BH only) (Source, Certainty-dimension)
   (comprehensible, coherent, plausible)
   [High]= cites multiple sources other than texts and scientists- particularly own knowledge

My Learning (Motivations)
7. How do you use knowledge? What does learning science or studying science mean to you?
   (M- career, self-efficacy) (Personal relevance, plausibility, commitment, comprehensibility)
   [High]=gives applications other than grades; notes relevant personal use
8. Do you feel you answered the investigative question fully in your argument and met the goals of this computer investigation? Explain. (M-Self-efficacy) (personal relevance)
   [High]= produces logical argument- states claim- presents evidence-explains
9. How did you like this type of activity? How do you feel about your learning during this activity? (M-Autonomy, competence) (social context)? (M-Intrinsic motivation) (need for cognition)
   [High]=genuine response; does not seem 'scripted'
10. What grade would you give yourself? Explain. (Self-efficacy, mastery goals) (need for cognition)
    [High]= produces logical argument- states claim- presents evidence-explains

Appendix B9: Activity and Intervention Questions

Activity 1  Questions

• What types of variations in these mantises do you see? These mantises are native to Ohio and many other states and can be found in a variety of habitats.

• How do these variations come about? Suppose you find two Carolina mantises (like #3) in the woods and three in an alfalfa field (like #4) in one week when you and your family were on vacation in various parts of the state.

• These mantises are said to be camouflaged. Predict what would happen if you rounded up all the mantises you found in the woods and set them free hundreds of miles away in an alfalfa field? Explain your answer.

One praying mantis female expends much energy and produces thousands of eggs each fall. (Not unlike many female insects of other species)

• What is the advantage of producing numerous offspring? Predict what might happen if a female mantis only laid a few eggs each year.

Intervention Question

• Fossil evidence and DNA analysis reveal that mantises and cockroaches shared a common ancestor about 30 million years ago. Explain how the forearm/claws of mantises could have come about.

Activity 2  Questions

• Make a hypothesis about how you think the two species of Paramecium will grow alone and how they will grow when they are grown together.

• Explain how you tested your hypothesis. (Include your data table in your journal)

• On what day did P. caudatum population reach the carrying capacity of the environment when it was grown alone? How do you know? P. aurelia?

• How do populations reach carrying capacity?

• Explain the differences in the population growth patterns of the two Paramecium species. What does this tell you about how P. aurelia uses available resources?

• Describe what happened when the paramecium populations were mixed in the same test tube. Do the results support the principle of competitive exclusion?

• Explain how this experiment demonstrates that no two species can occupy the same niche.

Intervention Questions

• Would all the individuals in the P. aurelia be the same? Think about this and explain your reasoning.

• Suppose the environmental conditions in the test tube were changing and there was less oxygen available because stoppers had been placed on the tubes. How might this change your results? Use the terms: variations, limiting factors, resources, differential survival

Note: Virtual lab questions adapted from open source lab from McGraw-Hill/Glencoe http://www.mhhe.com/biosci/genbio/virtual_labs/BL_04/BL_04.html
Activity 3 Questions
- How did limiting factors influence the finch population on Daphne major?

Intervention Questions
- How did some finches survive the catastrophe, while most finches did not?
- Why did some finches survive?

Activity 4 Questions
- Focus question: How does predation and the environment influence a population?
- Describe how the population of peppered moths changes when the environment background changes.

Intervention Questions
- How does variation in coloration affect the survival of an individual moth?
- How does variation in coloration relate to the moth's gene type?
- How do the genes in a population change over time? Explain how this happens.

Activity 5 Questions
- How do environmental factors influence a bug population over time?

Intervention Question
- Why do some bugs develop camouflage?
Appendix C: Student Data
Appendix C1: Individual Student Data and Analysis
Appendix C1: Andrew

Andrew (ECO+E) Explanations for Tasks - Ontological and Epistemological Beliefs

Task 1
The fox population has changed its fur color so that they could blend into the snow. If they were brown, things like bears and hunters could see them very easily. To prevent that from happening, they developed a mutation in their DNA so that their fur would change to a white fur. The white fur will allow the fox to blend in with the snow so such predators like the bear or hunter wouldn’t be able to see them as easily and their survival rate would increase.

Presupposition: Intentional goal, direct-process ontology
Suppositions: Teleological conception with proximate causation; synthetic model

Task 2
These populations have developed these features resulting from a mutation in the DNA. The population’s survival rate would increase if they could blend into the environment, or be camouflaged, because the predators wouldn’t be able to see or to find them. Developing a characteristic that makes them look like a different type of animal would be a good thing for a population because if they look like something else, then maybe the predators wouldn’t go after them because that’s not normally what they eat. The mutations are a big part to how a population survives because it either tricks the predator or make the predator think that they aren’t even there.

Presupposition: Intentional, goal, direct-process ontology
Suppositions: Teleological conception with proximate causation; natural selection concepts- variations, differential survival; synthetic model

Task 3
The change in color of the beetles resulted from two different things: predation and environment. The green beetles were getting eaten more than the brown ones so in order for the survival rate of the population to stay steadily where it is at, they developed a mutation in their genes. This mutation was passed on from generation to generation for many of years before the population color started shifting to brown. The reason brown was the adapted color was because the tree trunks are brown. To blend in to their environment, the mutation had to make them brown or they could still be seen by the predators. For the majority of the population to have this adaptation, it had to be passed through the genes for many of years!

Presupposition: Causal, goal, direct-process ontology
Suppositions: Teleological conception with proximate and ultimate causation; natural selection concepts-inheritance of variations, differential survival, population change with time; synthetic

Task 4
These particular animals have developed this trait through genetic variations passed down from generation to generation for many years! To ensure that their survival rate would be as high as possible, they either had to be not seen or trick their predator or prey. The color, size, and shape change is a direct result from this. Now, the population's genetic variation is part of the DNA so majority of the offspring will get this variation so that they can have a high survival rate as well.

Presupposition: Goal, terminal-event ontology
Suppositions: Teleological conception with proximate and ultimate causation; natural selection concepts-inheritance of variations, differential survival, population change with time

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.

Researcher notes: Student able to give explanations using proximate and ultimate causation. Explanations are teleological because student's presupposition and therefore conceptualizes evolution as more event-like.
**Andrew(ECO+E) Reflection - Ontological, Epistemological, and Motivational Status**

**Pre-Argument Reflection - Finches**

**Q-** How did limiting factors influence the finch population on Daphne Major? (Intervention)

One limiting factor that affected the finches was the lack of some food sources during certain seasons making some finches die when their main food source lacked. Some survived because their beaks allowed them to eat the food that was available while some did not have the trait to have beaks that could eat the available food.

**Ontological/Epistemological Status:**
- Proximate causation; enrichment/revision of ecological conceptions; linked trait (beak) to survival.

**Post-Argument Reflection - Finches**

**Q-** Why did some finches survive? (Intervention)

The survivors were well adapted to their environment. The parents had a variation that caused longer beaks so they could survive in the environment. When they had children, they inherited the longer beaks.

**Ontological/Epistemological Status:**
- Enrichment/revision of ecological conceptions; presupposition- causal, direct-process ontology, seems coherent, plausible explanation, committed.

**Pre-Argument Reflection - Bug Hunt**

**Q-** How do environmental factors influence a bug population over time? (Intervention)

The environment influences the bug population over time by changing the color of them. The bug will need to blend in and once a bug gets the gene, it’ll pass it down to their offspring so eventually, the whole bug population will look similar to the environment.

**Q-** Why do some bugs develop camouflage? (Intervention)

The environments influenced the bug population because the survivors would develop a mutation that causes them to blend in to the environment. When the bug had offspring, the offspring inherited the mutation causing them to be camouflaged as well. The bug had to decrease its size and change its color so that they could blend in and have a higher survival rate than they normally would. If they didn’t mutate, then the surviving rate would be a lot lower.

**Ontological/Epistemological Status:**
- Causal, direct-process ontology; alternative conception (implied) environmental induction of need-based mutation; proximate causation, enrichment/revision-inheritance of variations.

**Post-Argument Reflection - Bug Hunt**

**Q-** How do environmental factors influence a bug population over time? (Intervention)

The environment and predation plays huge roles in whether or not a bug lives or dies. If a bug is camouflaged, then the predators won’t be able to see them and they will live. If the bug is not camouflaged, then the bug will be seen by predators and will be eaten.

**Q-** Why do some bugs develop camouflage? (Intervention)

The individual bug was affected by predation because if they didn’t have the varied gene, they would increase their chance of being eaten. It affected the population because they varied their DNA so that way they could blend in so predation wouldn’t be a huge limiting factor.

**Ontological/Epistemological Status:**
- Causal, goal, direct-process ontology-presupposition; enrichment-predator/prey relationship and camouflage; proximate causation; ontology seems coherent, plausible explanation, committed.
Post Argument
Q- Is your claim scientific? Explain.
   GF- Yes because it was has evidence and reasoning to support the claim. [High]
   BH- Yes, my claim is scientific because it has evidence and justification to back up the claim. The justification relates the evidence directly to the claim because it explains how the evidence has anything to do with the claim. [High]
   Suppositions: High justification/source dimension; Task - comprehensible, coherent.

Q- What evidence did you use to support your claim?
   GF- We used graphs from the website and our previous knowledge about DNA, mutations, and variations. [High-evidence]
   BH- The evidence that I used to support my claim was how the bug adapted with the mutation that it had. In order to survive, the bug had to change its size and color so that it could be camouflaged with its environment. [High-cited evidence]
   Suppositions: High-source-knowledge internal; Task -comprehensible; Implied -social context motivating; Presupposition-intentional, goal-event ontology.

Q- Did your claim change when you saw conflicts in data during your argument? Explain.
   GF- No because in science, there are always going to be exceptions and nothing is set in “stone”, meaning science changes constantly. [High-evolving]
   BH- No because if in every environment, the bugs that weren’t well camouflaged were eaten first so I know that my claim was a permanent one for me. [Low-right answer]
   Suppositions: High development/Low-certainty beliefs; Task plausible and rhetorically compelling; Presupposition-intentional, goal-direct-process ontology.

Q- Where there any patterns in the evidence? Give specific examples if necessary.
   GF- Yes because there were typically more finches observed in the wet season than in the dry season. [Low-lack use of evidence]
   BH- Yes. In every environment, the bug size reduced so they’d be harder to see. Also, the color, hue, and saturation changed so that the bug could be camouflaged with its background and be harder to see. [High-evidence]
   Suppositions: Mixed-source/justification beliefs; Task plausible and rhetorically compelling; Presupposition-intentional, goal-direct-process ontology.

Q- How is your argument similar to an argument a professional scientist would make?
   GF- It supported by evidence and reasoning that was observed and collected by other scientists and we just built on it. [High-certainty/development]
   BH- My argument is similar to an argument a professional scientist would make because we both would have evidence. Along with the evidence, we both have justification that links or tells why the evidence is important to the claim that we have.[High-certainty]
   Suppositions: Both arguments high certainty/development dimensions; high motivations - need for cognition/intrinsic motivation - social context.

Q- Where do you find scientific knowledge?
   BH- Anywhere that you could find clues about what you are doing. In this project, we could have found the scientific knowledge by seeing what happens to populations when the get in danger. They could mutate so that they could have a higher survival rate. [High-internal knowledge]
   Suppositions: High source belief; intentional, direct-process ontology.

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
   BH- Learning science means quite a bit to me because the profession I’d like to be is in the scientific field. I will use this knowledge to better prepare myself for what I will have to do in the future. [High]
   Suppositions: High in personal relevance; rhetorically compelling
Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?

GF- Yes because we answered the questions directly in our claim and supported them with evidence backed up by reasoning that linked our claim to the evidence. [High]

BH- I would say I did because I made sure I used plenty of evidence and justification so that I could describe it to the full intent of the complex answer. [High]

Suppositions: High in self-motivations- self-efficacy and self-determination/ personal relevance

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- I found this fun and would like to do more because the data gives you the facts so you know for sure that the answer is correct because you pulled the answer directly from the data supplied. I felt like I did learn a lot from this activity, but, I did use a lot of my pervious knowledge to answer some of the questions. I only got frustrated once and that was at the beginning when we weren’t sure exactly what to do. [Low]

BH- I felt this activity was a bit difficult. I was pretty frustrated at first because I wasn’t really sure what I was supposed to do. If I understood right from the beginning, I think I would have liked it more. [Low]

Suppositions: Low in autonomy/ self-determination; high in social context and source dimension-individual knowledge generation.

Q- What grade would you give yourself on this activity? Explain.

GF- I would give us an “a” because we answered the questions thoroughly and used the evidence to back up our answers on every question. [High]

BH- I would give myself a “A” or around a 93% because I worked really hard on what I was doing and also, I used as much evidence as I could. [High]

Suppositions: High in self-motivations- self-efficacy, grade motivation, need for cognition/intrinsic motivation

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bgule.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:

ONTOLOGY/EPISTEMOLOGY
Student's ontological presuppositions are coherent, direct processes with varying features, primarily intentional and goal. Student's written explanations all reflect this ontology and are reflected in his consistent teleological propositions or narratives. Student shows basic understanding of proximate causation for variations and basics of inheritance of characteristics. Epistemic beliefs are rated overall high (9/1=82%), shows basic understanding of nature of scientific knowledge. This is congruent with student's average pre-, post-survey scores on SEB (4.37=87%). Mental Model- student's ontological and epistemological framework structure is coherent, network-like. Improvement in declarative, evolutionary conceptions throughout from Pretest to Final Test (50%-75%). Continued revision through Final Test (82%). Concept map structure reveals improvement in interconnections among concepts. Student showed enrichment and revision of evolutionary conceptions from Pretest to Posttest with increased development of evolutionary propositions of 25% (3/6 to 6/8). CINS scores showed only minimal gains of 1 from 9/20 to 10/20. Proposition quality score increased from 1.6 (pretest) and 2.2 (posttest) to 2.3 on final test.

MOTIVATIONS
Mixed results (2/4) on self-motivations; student's written reasoning suggest that he has high self-efficacy and can defend his claims through argumentation. However, student displayed lower characteristics of autonomy and self-determination. Student is academically high and has grade motivations (3/3), but because of the nature of previous passive-student experiences, he becomes frustrated when given autonomous experiences like more guided, open inquiries. Student self-scores on SEB showed high motivations in average score (4.25=85%).
Andrew (ECO+E) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Carrying capacity is the largest number of individuals of a population that a given environment can support.
Many populations make up an ecosystem.
Many individuals of a species make up a population,
Limiting factors affects the differential survival rate, or survival rate.*
Reproduction results in an increase of population.*
Limiting factors results in a decrease of population.*

Total Propositions=11; Scientific Propositions =6(55%); 3/6=Evolutionary (50%)

Scientific Propositions (Posttest)
Populations make up ecosystems.
Individual Organisms make up many populations.
Individual Organisms are made up of genes passed down from their parents.*
Heredity traits are passed through individual organisms.*
Genes are passed down through reproduction.*
Changing environments can affect the carrying capacity either positively or negatively.*
Changing environments creates limiting factors for a population or species.*
Limiting factors cause the carrying capacity to decrease.*

Total Propositions=17; Scientific Propositions=8(47%); 6/8=Evolutionary (75%)

Scientific Propositions (Final Test)
Ecosystems can only carry a certain amount of each species, which is called carrying capacity.
Individual organisms of a species make up populations.
Populations of different species make up an ecosystem.
Reproduction can increase populations.*
Limiting factors cause a decrease in populations.*
Genetic variations can be inherited through reproduction.*
Reproduction can pass traits down through a process called heredity.*
Changing environment can either positively or negatively affect a population’s carrying capacity.*
Individual organisms compete against each other in differential survival.*
Changing environments can affect each and every individual organism.*
Genetic variations can be passed through the organisms of a population.*
Limiting factors can slow the rate of a population’s reproduction.*

Total Propositions=19; Scientific Propositions=12(63%); 9/12= Evolutionary (75%)

Note: Evolutionary Propositions are noted with *
Andrew(ECO+E) Concept Map Structures with Cognitive Map

Pretest- Hub/Spokes Structure

Cognitive Map

Posttest- Network Structure

Final Test- Network Structure
Appendix C1: Ann

Ann (ECO+E) Explanations for Tasks-Ontological and Epistemological Beliefs

Task 1
The white fox is camouflaging in the winter which is why it's easier to spot the brown fox because of course the winter being as white as it is so it's easier for the white fox to blend in with his environment. The brown fox is easier to spot cause he is more darker and its more likely for him to die off first.

Presupposition: Intentional- direct-process ontology
Suppositions: No explanation; gives descriptions-no direct connection with predation.

Task 2
How these particular animal populations develop these features is the genes in the bugs DNA, which they can blend in with their environment which makes the predators and prey difficult to see. The bugs that can survive longer than other bug that don't blend in with the environment can live longer.

Presupposition: Terminal- direct-process ontology
Suppositions: Proximate causation/ refers to individual; emergent natural selection concepts-variation, differential survival.

Task 3
How the proportions of beetles in the forest have change is the forest is more greener so the green beetle is blending into his habitat. Most birds are going to have a hard time finding it. Brown beetles several years ago could blend in. Now with time changing birds can focus and see them more, which their dying off, and less brown beetles. Both green and brown beetles are camouflaging into the environment because of the genetics they produces in their body. So with all of this camouflaging it’s dependent on either if the brown or green beetle will survive.

Presupposition: Terminal- direct-process ontology
Suppositions: Evolutionary conception; implied evolutionary change in population over time; proximate causation; natural selection concepts-variations, differential survival.

Task 4
How these animals or bugs developed these features in the gene in their body that was produced causing them to camouflage into their natural habitat or environment. With the bugs or animals camouflaging it’s harder for their predators to find them and kill them. The animals and bugs it’s more easier for them to find food cause there prey can’t see them. There camouflaging into their environment so more food for them.

Presupposition: Terminal- direct-process ontology
Suppositions: Proximate causation/ refers to individual; natural selection concepts-variation, differential survival.

Notes: Italicized phrases and words are coding; Punctuation and spelling corrected.

Researcher notes: Student able to give explanations using proximate and ultimate causation. Explanations are not teleological. Student's presuppositions show more terminal-direct process categorization. Shows basic mechanistic understanding of source of variation and differential survival.
**Ann (ECO+E) Reflections-Ontological, Epistemological, and Motivational Status**

**Pre-Argument Reflection- Finches**

Q-How did limiting factors influence the finch population on Daphne Major?
Q-How did some finches survive the catastrophe, while most finches did not? (Intervention)

The finches didn’t survive the catastrophe in 1977 because of the food/seeds they ate during the wet and dry seasons. Finches with bigger beaks were able to dig deeper into plants to get more seeds. So they had a better chance of surviving.

How the finches could survive was the longer beak they had the easier it was for them to find food.

**Ontological/Epistemological Status:**

Enrichment/revision-ecological conceptions; incorrect causation for beaks (finding for cracking).

**Post-Argument Reflection- Finches**

Q-How did limiting factors influence the finch population on Daphne Major?
Q- How did some finches survive the catastrophe, while most finches did not? (Intervention)

Because there was a limited amount of food. Finches with bigger beaks survived the catastrophe. How some birds survived was with the longer beak they could crack the seeds and those with the smaller beaks died off. The characteristics was the beak length those with the long beak had much easier time crushing the seeds than those with a smaller beak size so most died off or had trouble finding other food.

Q- Why did some finches survive? (Intervention)

Finches with bigger beaks survived the catastrophe of 1977. In 1977 there was a drought and finches had to eat seeds instead. Why some finches couldn’t survive was if some finches had smaller beaks it was either harder for them to crack the seeds or the finches had trouble finding other food to eat if not they would probably die off.

**Ontological/Epistemological Status:**

Revision beaks function (cracking); proximate causation

**Pre-Argument Reflection- Bug Hunt**

Q- How do environmental factors influence a bug population over time?

How the environment influence bug population over time is it didn’t increase nor decrease. It depends on bug size, bug population, the color, and the environment.

Q- Why do some bugs develop camouflage? (Intervention)

No Response

**Ontological/Epistemological Status:**

Incoherent/inaccurate response; impossible to determine from data

**Post-Argument Reflection- Bug Hunt**

Q- How do environmental factors influence a bug population over time?

How the environment influences a bug population over time is how they survive in the environment. If it camouflages into the environment there should be an increase on the bug population and if the bug doesn’t camouflage into the environment there will be a decrease in population.

Q- Why do some bugs develop camouflage? (Intervention)

Why bugs develop camouflage is a gene in the bugs DNA and it blends in their habitat or surroundings. If the bugs camouflages into the environment the bug survives longer. If the bugs don’t blend into their environment then they will not survive

**Ontological/Epistemological Status:**

Enrichment of ecological conceptions; proximate causation; implied individual adaptation;

Presupposition- Intentional- direct-process ontology; ontology seems coherent, plausible explanation, epistemologically commitment
Q- Is your claim scientific? Explain.
   GF- Yes it relates to how some seeds grow during different times of the year. Our group had a lot of evidence such as a graph that showed the characteristics of seeds types for the finches. [High-evidence]
   BH- I think our claim we did was scientific because our group was determining how bugs survive in their natural habitat by blending in so that the bugs live longer. How the claim was scientific was our group used evidence to back up our answer on why bugs camouflage in their habitat. [High-evidence]
   Suppositions: High-source and justification, as well as value-social context ‘our’; Tasks-comprehensible; shows coherency in source belief

Q- What evidence did you use to support your claim?
   GF- The evidence our group used was the beak length and how it varied between finches, why it was an advantage was the beak could crack the seeds for them to eat it, how the rainfall affected the seed growth in either the dry or wet season, characteristics about the seeds and the length and volume and how rigidity the seeds were. And lastly food that was also available for the finches and it was seeds cactus. [High-evidence]
   BH- Our evidence that we used to support our claim was the graphs that show the time, bug size, carrying capacity, environment background, and the mutation. [High-evidence]
   Suppositions: High-source/certainty dimensions; cited evidence; High-social context; Tasks-comprehensible, plausible; coherent conceptions-proximate causation.

Q- Did your claim change when you saw conflicts in data during your argument? Explain.
   GF- No, because the article about the finches was about the catastrophe and the different seeds and how the finches survived and didn’t survive. [Low-refer to authority/ certainty]
   BH- No our claim didn’t change during the modeling question because our group knew that the bugs in order the survive was to camouflage in their natural habitat to survive longer. [High-internal knowledge/certainty]
   Suppositions: Mixed-source/certainty dimension rating; Goal-direct-process ontology.

Q- Where there any patterns in the evidence? Give specific examples if necessary.
   GF- All the evidence that we collected about finches goes back to food/ seeds that finches can eat. [Low-descriptive only]
   BH- Yes, the mutation always stayed the same. [Low-no citing of evidence]
   Suppositions: Low justification/source dimensions; did not support reasoning

Q- How is your argument similar to an argument a professional scientist would make?
   GF- My argument is similar to an argument to a professional scientists would make because I used evidence to support my answers and my claim, and justification of checking over everything that I supported. [High-evidence]
   BH- How is our argument similar to an argument of a professional scientist is because our group used experiments and information as well as background information to gather and use as evidence into our argument. [High-evidence]
   Suppositions: High-certainty/development dimensions; High-self-motivations/self-efficacy and social context

Q- Where do you find scientific knowledge?
   BH- You find scientific knowledge in some scientists arguments they try to base there knowledge on. What we can include about the scientific knowledge is that it’s just a predicament based on evidence. [Low-refer to authority]
   Suppositions: Low-source dimension; refers to authority

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
BH- No response [Low]

Suppositions: no response- unable to determine

Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?

GF- How I feel about the investigate question is I supported my claim and evidence by making graphs and meet the goals of this investigation. [High]

BH- Yes because the group gave evidence that supported the investigative argument and it met the goals of this computer activity. [High]

Suppositions: High-social context; high-self efficacy

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- How did I like using the data to find the evidence is it helped understanding about using the claim and making evidence. I also liked using data to find answers cause it made me better understand finches and how they can survive.

How I feel about my learning of this activity was I learned much information about the finches and how they can and can't survive. I think it added to my knowledge very well. I was frustrated on a couple questions but nothing severe I think. I thought it was definitely fun and I can't wait to learn even more information about finches. [High]

BH- I thought this computer modeling activity was good I understood the bug population and the graphs were helpful.

How I feel about the learning and this activity is fine I thought it was very interesting to learn about how bugs can camouflage themselves in their environment and live longer. During this activity there was times were it would get a little frustrating but our group pulled through and it turned about to be a great learning experience. [High]

Suppositions: High- autonomy/self-determination/ intrinsic motivation/need for cognition; High social context

Q- What grade would you give yourself on this activity? Explain.

GF- I think I should deserve at least no greater than a B because I tried my best gave good effort and participated and all ended very well. [High]

BH- The grade I think I would give myself would be at least high C or maybe B if possible. [Low]

Suppositions: Higher self-efficacy and grade motivation in GF; did not provide reasoning in BH.

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:

ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS

Ontology/Epistemology

Student's ontological and epistemological presuppositions seem coherent, event processes with varying features, primarily terminal.

Student's written explanations all reflect this ontology and are reflected in her consistent proximate causation reasoning in narratives. Student shows basic understanding of mechanism for variations and differential survival of individuals.

Epistemic beliefs are rated overall high (7/11=64%), shows minimal to satisfactory understanding of nature of scientific knowledge. These scores are close to the final score on SEB (3.57/5=71%).

Motivations

Results (4/4) on self-motivations indicate; student's written reasoning suggests that she has high self-efficacy and can defend her claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about her work within the group.
persistence when given more autonomy in inquiries. Overall her motivational score on the survey improved (mean gain (0.39) from 3.87 to 4.26. Student struggles academically in school and has lower grade/career motivations (1/3).

Mental Model- student's ontological and epistemological framework structure is developing and she seems to be forming new connections between concepts with improvement in declarative, evolutionary conceptions throughout intervention (0%-80%). She did not develop any scientific propositions on her pretest and only had 2/16 scientific propositions on her posttest. She shows enrichment and revision of conceptions through Final Test producing 5/10 scientific conceptions (50%) and 4/5 evolutionary conceptions. Concept map structure reveals a slight improvement in interconnections among concepts. When she was forced to create connections from her cognitive map structure, she produced only two scientific propositions from 16 (2/16=13%) propositions that she had to create. Interestingly, her CINS score improved from a score 5 to 14 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development.

---

**Ann (ECO+E) Declarative Knowledge from Concept Mapping Propositions**

<table>
<thead>
<tr>
<th>Scientific Propositions (Pretest)</th>
<th>O Scientific Propositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Propositions=9; Scientific Propositions =0; 0=Evolutionary (0%)</td>
<td></td>
</tr>
</tbody>
</table>

| Scientific Propositions (Posttest) |
| Changing environments effects individual organisms on their survival rate.* |
| Changing environments can cause limiting factors in an ecosystem.* |
| Total Propositions =16; Scientific Propositions=2; 2/2=Evolutionary (100%) |

| Scientific Propositions (Final Test) |
| Limiting factors limit the population from increasing.* |
| Carrying capacity is the maximum amount of organisms that can live in an area. |
| Mutations in our genes produce population changes over time.* |
| Reproduction can cause a population to grow.* |
| Genes are passed on the next generation which is heredity.* |
| Total Propositions=10; Scientific Propositions=5; 4/5= Evolutionary (80%) |

Note: Evolutionary Propositions are noted with *
Ann (ECO+E) Concept Map Structures with Cognitive Map

Pretest-Circular Structure

Cognitive Map

Posttest-Network Structure

Final Test-Tree/Net Structure
Appendix C1: Bill

*Bill (ECO+E) Explanations for Tasks-Ontological and Epistemological Beliefs*

**Task 1**

Now that *generations have past*, we would see that the proportion of white to brown is way higher. There are much more white than brown now because predation upon the foxes has killed off many of the brown foxes, because they were able to be spotted easier. Over time, the *amount of white foxes rose* because *they had the adaptation* for white fur instead. Just like the finches from the other activity *gained longer beaks*, because the ones with shorter beaks were killed off during the drought.

*Presupposition:* may have emergent-process ontology

*Suppositions:* Evolutionary explanation; change in population over time; natural selection concepts-variation, differential survival.

**Task 2**

Over time, they have developed these adaptations that increase their chances of survival. *Little by little over thousands of years, these traits became more prominent among the species* as more and more of that species gained the trait due to the ones lacking that trait dying because they didn’t have the necessary adaptations to survive. This results in the *trait to be much more abundant among the species over time*, because with time, more and more are born with this trait.

*Presuppositions:* possible emergent-process ontology;

*Suppositions:* Evolutionary explanation; change in population over time; natural selection concepts- inheritance of variations, differential survival.

**Task 3**

Due to the *birds being able to spot the green beetles more easily*, that color of beetle was *eventually lost due to over predation*, meaning that the gene for green colored beetles was lost, and *taken out of the gene pool*, resulting in many more brown beetles because they *had the adaptation to survive*, while the green beetles did not.

*Presuppositions:* more-direct-process ontology;

*Suppositions:* Evolutionary explanation; change in population over time; natural selection concepts-variation, differential survival.

**Task 4**

*Over time, these species have developed these adaptations in order to survive.* When the individuals without the adaptations die, *that trait is eventually taken out of the population or gene pool*, and replaced with an adaptation that allows the species to survive and escape from predation. *Over time, the population may all have these adaptations, simply because the ones without the adaptation all died due to predation.* The bugs from the bug activity we did, eventually all had around the same color or size, *because that particular color or size, was least vulnerable to predators*, just the same as other animals around the world gain adaptations for survival.

*Presuppositions:* possible emergent ontology

*Suppositions:* Evolutionary explanation; change in population over time; natural selection concepts- inheritance of variations, differential survival. Suggestion of teleological thinking in first declaration, but further description clarifies conceptions.

**Notes:** Italicized phrases and words are coding; Punctuation and spelling corrected.
**Bill (ECO+E) Reflections-Ontological Epistemological and Motivational Status**

**Pre-Argument Reflection- Finches**

Q-How did limiting factors influence the finch population on Daphne Major?

The food supply changed, because of the extra dry season during 1977, there was less food for the finches, meaning that finches with the long beak were able to get more food than the short beaked finches because they had an advantage with the longer beaks. Because some finches had longer beaks and were able to compete for food better than the short beaked finches. The offspring in 1978 would have longer beaked fledglings because the parents that survived the catastrophe had long beaks, and eventually reproduced.

**Ontological/Epistemological Status:**
Enrichment-ecological conceptions; proximate causation; natural selection concepts-variation, differential survival, inheritance

**Post-Argument Reflection- Finches**

Q-How did limiting factors influence the finch population on Daphne Major?

The graphs showed that populations of the finches with short beaks begin to die because they are unable to compete for food during the dry season of 1977. The 3 seasons (Dry 76’ – Dry 77’) when there was very little to no rainfall, these are the same seasons where the finch population seemed to decrease a more rapidly. This rainfall shortage would cause dry environments and low plant population and low food shortage. During the Dry 76’ and Dry 77’ many finches were having trouble finding seeds to eat. Some would go long periods of time without finding food. The finches that survived had certain traits that allowed them to survive through the catastrophe, such as longer beaks to obtain food easily. The ultimate trait that allowed some birds to survive was the beak size. The advantage from having a longer beak is that they were able to find food much easier, and were able to compete better for the food and living space on the island.

Q- Why did some finches survive? (Intervention)

The factor that allowed some finches to survive the catastrophe was the longer beaks. Long beaked finches survived, while others died. The finches would have to develop stronger beaks in order to break the seeds open and get the necessary food to survive.

**Ontological/Epistemological Status:**
Goal orientation; teleological conception - implies individual adaptation. Enrichment/revision-ecological conceptions; proximate causation; natural selection concepts-variation, differential survival; ontology seems coherent, plausible explanation, committed.

**Pre-Argument Reflection- Bug Hunt**

Q- How do environmental factors influence a bug population over time?

If the environment has a high carrying capacity the higher the bug population will be. The bugs can develop adaptations to increase survival. If the bugs don’t can’t blend into the environment well, predators will be able to see them easily, meaning that survival rates aren’t very high.

Q- Why do some bugs develop camouflage? (Intervention)

The population is influenced by the environment because the colors and traits of the population change, depending on how many in the population have adaptations that let them survive, such as color and camouflage.

**Ontological/Epistemological Status:**
Goal-event ontology-presupposition; teleological conception - implies individual adaptation. Enrichment/revision-ecological conceptions; natural selection concepts-variations, differential survival

**Post-Argument Reflection- Bug Hunt**

Q- How do environmental factors influence a bug population over time?
The environment affected survival because if the bugs were unable to blend with the environment, they were eaten by predators. The predators affected the traits of the population because they killed bugs with certain traits, and kept the reproduction of the population under control. It makes bugs adapt over time in order to survive, to escape from predators using camouflage, they use the environment to blend in.

Why do some bugs develop camouflage? (Intervention)
Depending on certain traits some bugs were easily caught by predators making those traits less common in the population. They develop camouflage to escape predation in order to survive and reproduce. Genes from the prey that were eaten, were taken out of the gene pool, meaning that when the following generations reproduced, only the survivor’s genes were passed on to the next generation.

Ontological/Epistemological Status:
Goal- orientation; teleological conception - implies individual adaptation; natural selection concepts- variation/traits, differential survival, inheritance; ontology seems coherent, plausible explanation, committed.

Post Argument
Q- Is your claim scientific? Explain.
  GF- Yes, because it used evidence based on studies of these finches in order to make the claim. [High]
  BH- It is scientific because it uses the evidence from the computer modeling in order to make a scientific conclusion about the data. [High]
  Suppositions: High-source and justification dimensions; Task comprehensible, conceptions coherent

Q- What evidence did you use to support your claim?
  GF- I used evidence from the studies of the Galapagos Finches and the changes in their population over time. [Low- lack specific examples]
  BH- We had evidence from the computer modeling, such as bug color, bug size, mutation speed, and higher carrying capacities in the environment. Each of these variables all supported our claim about the bugs population. [High-cited specific examples]
  Suppositions: High source and justification dimensions; Task comprehensible, conceptions coherent

Q- Did your claim change when you saw conflicts in data during your argument? Explain.
  GF- When you analyze the data and realize that the finches with longer beaks survived, it leads you to believe that this was the reason for their survival. [High-certainty]
  BH- Yes, because when we began to change more variables, the data changed, ultimately changing our claim about the data as a whole. [High-development]
  Suppositions: High-development/ certainty dimension; Task comprehensible; conceptions coherent; dissatisfaction

Q- Where there any patterns in the evidence? Give specific examples if necessary.
  GF- The evidence leads you to believe that birds that died in the catastrophe did not have the traits needed in order for survival. [Low- cited no evidence]
  BH- Yes, because with each changing variable, you can observe what the variable actually affected, such as changing carrying capacity, allowed for predators to have more prey to eat. [High-evidence]
  Suppositions: Mixed source/justification dimension; natural selection concepts- variation/ traits, differential survival

Q- How is your argument similar to an argument a professional scientist would make?
  GF- My argument is based off of evidence from a creditable source, which is similar to what a real scientist would do daily. [High-development]
  BH- Because just like an actual scientist would, my partner and I both used data from a model to create a claim and use the data as evidence to justify the claim. [High-certainty]
Suppositions: High-certainty/development dimensions; high-autonomy/self-determination and self-efficacy

Q- Where do you find scientific knowledge?
   BH- You can find it anywhere, the internet, being a primary source of knowledge around the world today. It is based on fact and claims, backed up by evidence and justification. [Low-refers to outside]
   Suppositions: no mention of personal ability to knowledge

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
   BH- I will use this knowledge to make educated claims about the world around me. Learning science is learning how to use data around you, to for hypothesis’s and claims. [Low-not personally relevant]
   Suppositions: general claim/ low personal relevance

Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
   GF- Yes, because my argument uses data presented by the study and links the evidence of that study to the claim. [High]
   BH- Yes, because we used data from the model to support and justify our claim. [High]
   Suppositions: High-self motivations/ self-efficacy, autonomy/self-determination; high-justification

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?
   GF- I liked it because it allowed me to use information given to me to prove a point. At some points it was frustrating, but for the most part it was pretty fun being able to use data on the computer, gathered by someone else, to make your own claim about the data. [High]
   BH- I liked being able to observe how changing one variable can affect an entire population. I thought it was pretty fun, you got to do exactly what scientists do in the real world every day. [High]
   Suppositions: High- personal relevance, autonomy/ self-determination, self-efficacy/need for cognition

Q- What grade would you give yourself on this activity? Explain.
   GF- I would give my partner and I a high B or an A, we both put a lot of work into the presentation of the data, as well as developing our argument. [High]
   BH- I would give [Partner] and I an A or high B, because we used the data collected to form a claim, and back it up with evidence, the correct way a scientific argument should be. [High]
   Suppositions: High- self efficacy, grade motivation, personal relevance, intrinsic motivation/ need for cognition

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations: ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS
Ontology/Epistemology
Student's ontological and epistemological beliefs seem vary. Reflections revealed goal-event teleological conceptions-implies individual adaptation. Did not give teleological narratives on tasks. Perhaps students are learning the vocabulary of descriptions; student 'knows' and expresses that individuals cannot willfully adapt but student 'writes' it; Is negotiation part of the process of lifting presuppositions? Student's written explanations all reflect this ontology and are reflected in his consistent proximate causation reasoning in narratives. Student explanations for tasks show understanding of mechanism for variations and differential survival, and population change with time. Epistemic beliefs are rated overall high (8/11=73%), shows satisfactory understanding of nature of scientific knowledge. These scores are lower than the self-reported final score on SEB (4.37/5=87%).
Motivations: Results (4/4) on self-motivations indicate; student's written reasoning suggests that he has high self-efficacy and can defend her claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about his work. Response to personal relevancy scored low on career motivation (2/3) with two high scores in grade motivations. He reported that he liked both inquiries and enjoyed autonomy. Displayed persistence when given more autonomy in inquiries. Overall his motivational score on the post survey was lower mean loss (-0.42) with an average score of 3.9 (78%). This score is similar to the reflection score of 86% (4/4+2/3=6/7).

Mental Model- Student's ontological and epistemological framework structure seems network like with connections between concepts. There was improvement in declarative, evolutionary conceptions throughout tested period (70%-85%). He shows enrichment and revision of conceptions through final test. Seven of 10 scientific propositions were evolutionary on the pretest, 7 of 9 (78%) evolutionary conceptions on the posttest(78%) and 11/13(85%) evolutionary conceptions on the final test. His CINS score improved from a score 9 to 10 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development

Bill (ECO+E) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Environmental changes can affect the differential survival of organisms.*
Individual organisms live in the ecosystem best fit for their survival.*
Individual organisms can have mutations in their genes, making them different from other organisms of the same species.*
Genes can sometimes get mutated to change the coding of the gene.
Genes from both the mother and father are put together during reproduction to for an offspring's DNA*. 
Limiting factors of an environment can affect the reproduction rate.*
Reproduction influences the population to increase or decrease.*
Carrying capacity is the maximum amount a population can have in an environment.*
Populations make up ecosystems.
Populations can change, depending on the changing environment.
Total Propositions=12; Scientific Propositions =10; 7=Evolutionary (70%)

Scientific Propositions (Posttest)
Mutations can sometimes be inherited through heredity.*
Individual organisms make up populations.
Changing environments can often change the makeup of an ecosystem.
Populations can change depending on the changing environment.*
Genes depend on the change in the environment, the genes in the gene pool can change over generations in order to adapt to the new changing environment.*
Reproduction can increase or decrease the size of a population.*
Genes from both mother and father are put together to form an offspring during reproduction.*
Reproduction can sometimes result in mutations.*
Genes sometimes develop variations, resulting in genetic variation.*
Total Propositions =17;Scientific Propositions=9; 7/9=Evolutionary (78%)

Scientific Propositions (Final Test)
Changing Environments can affect the differential survival of organisms.*
Individual Organisms live in the ecosystem best fit for their survival.*
Individual Organisms can have Mutations in their genes, making them different from other organisms of the same species.*
Genes can sometimes get mutated to change the coding of the gene.*
Genes from both the mother and father are put together during reproduction to for an offspring's DNA.*
Limiting Factors of an environment can affect the rate of reproduction.*
Reproduction influences the population to increase or decrease.*
Carrying capacity is the maximum amount a population can have in an Ecosystem.
Populations make up ecosystems.
Populations can change, depending on the changing environment.*
Genes can sometimes develop mutations over time.*
Genes can develop changes over time within a species, resulting in genetic variation.*
Population size is determined by the amount of limiting factors.*
Total Propositions=18; Scientific Propositions=13; 11/13 = Evolutionary (85%)
Note: Evolutionary Propositions are noted with*

Bill (ECO+E) Concept Map Structures with Cognitive Map

Pretest-Circular Structure

Cognitive Map

Posttest-Network Structure

Final Test-Network Structure
Appendix C1: Brea

**Brea (ECO+E) Explanations for Tasks-Ontological and Epistemological Suppositions**

**Task 1**

The proportion of foxes living in northern Europe has changed by the *mutations that occur in the foxes’ genes so that they have a higher survival rate*. The brown foxes did not survive well, so they did not reproduce well. But the white foxes had a high survival rate because they were harder to see, so they could reproduce more. The new generations of white foxes *adapted to their environments by mutating* and through gene switches since the foxes did not survive well when they were brown.

**Presupposition:** Goal- direct-process ontology  
**Suppositions:** Teleological conception with proximate causation; enrichment unknown; natural selection concepts-variations, differential survival

**Task 2**

These particular species *developed these essential features so they could survive better* and have camouflage. Camouflage helps animals blend into their environment so that the predators that eat the animals won’t be able to see them and the prey they eat won’t be able to see them coming and escape them. When they did not have this camouflage, the species had a lower survival rate because they were eaten a lot and didn’t get to hunt other species because their prey could see them coming. But the generations that did not have this camouflage went through mutations and genes switches *until they acquired the right camouflage that blended them in with their environments perfectly*; eventually this lead to a higher survival rate of the certain species.

**Presupposition:** Goal- direct-process ontology  
**Suppositions:** Teleological conception with proximate causation; natural selection concepts-variation, differential survival, change through time

**Task 3**

The proportions of the beetles have changed by adapting to their environment. The brown beetles *were able to blend in with their surroundings*, but the green ones stuck out and made it easier for their predators and their prey to see them. The green beetles were eaten by their predators and since they did not blend in, their prey could see them coming, so they were not able to get enough food to survive. The green beetles have mostly all died off, while the brown beetles have thrived due to their ability to blend in with their environment for survival.

**Presupposition:** Terminal- direct-process ontology  
**Suppositions:** Proximate explanation; natural selection concepts-variation, differential survival, change through time

**Task 4**

These animals have developed these features by being influenced by their surroundings. They *needed to blend in* so that they could survive better, and the only way to do that was to adapt to their environment and develop a camouflage that allowed them to be hidden from their predators and prey. *Throughout the generations, little by little, their genes change to allow them to survive the best.* It takes awhile to fully transform into what they need to look like for their best survival rate but eventually they are successful and they stick with that form to survive best.

**Presupposition:** Goal-direct-process ontology  
**Suppositions:** Teleological conception with proximate causation; natural selection concepts-variation, differential survival, change through time

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.
Pre-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Q-How did some finches survive the catastrophe, while most finches did not? (Intervention)
Some finches survived because they adapted to the environment better, like beak size, wing length, leg length, and weight. There was a mutation in the genes due to the lack of survival of the last generation. The correct mutations occurred in the finches genes so that their traits varied enough so that they could be ideal for survival.
Ontological/Epistemological Status:
Terminal, goal-direct-process ontology; proximate reasoning-faulty.

Post-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Q- How did some finches survive the catastrophe, while most finches did not? (Intervention)
The bigger beaks mean they could widen the variety of food they eat and crack seeds better. The longer legs meant they could walk more and run faster. The wider wing-span meant the finches had a better flight ability. And the lower weight helped them in all prospects. Because some finches had the necessary mutations and genetic changes required for their survival. They were well proportioned in their beaks, legs, wings, and weight, which made it ideal for them to survive.
Q- Why did some finches survive? (Intervention)
Because they had the essential changes to their genes that made it so they could adapt better and survive under the constant changing of the weather and environment.
Ontological/Epistemological Status:
Intentional-direct-process ontology; enrichment- ecological conceptions; proximate causation; ontology seems coherent, plausible explanation, committed.

Pre-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
Depending on the environment the bugs will mutate helping the population grow or at least stay constant over time.
Q- Why do some bugs develop camouflage? (Intervention)
Some bugs develop camouflage because in order to survive they have to mutate over time to blend in to their environment. So their environment is very essential to them because they depend on it to blend in to survive. The more time the bugs have to mutate the better camouflage they develop and the more they adapt to their environment. Also, depending on the environment and where they can blend in or hide, determines how and what mutates, for example size and color.
Ontological/Epistemological Status:
Goal-direct-process ontology; alternate conception-purposeful mutation from environment (non-epigenetic); enrichment-ecological conceptions.

Post-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
The environment causes the bugs to mutate and the ones that don’t have the ability to mutate the right way to survive die off. Predation determines the survival of a bug because based on the camouflage of the bug and whether they blend into their environment or not, they harder or easier it is for their predators to see.
Q- Why do some bugs develop camouflage? (Intervention)
So that they can blend in to their environment and survive from predators and they can hide from their prey so the prey doesn’t see them coming.
Ontological/Epistemological Status:
Goal-direct-process ontology; alternate conception-purposeful mutation (non-epigenetic or toxic/electromagnetic mutagenic) from influence of environment. ontology seems coherent, plausible explanation, committed. Synthetic model***

Post Argument
Q- Is your claim scientific? Explain.
GF: Yes, because we took data and used that and evidence from our research to make the best. [High]
BH: Yes because I used real data from the experiments I carried out. I used my research and data that was valid and strong. [High]

Suppositions: High-source/justification; High-social context; Task-comprehensible; conceptions coherent

Q: What evidence did you use to support your claim?
GF: The information we got from the field notes on the website we used. Such as, the changes in the finches' traits and how the ones that died were different from the ones that survived. [High-evidence]
BH: We said that size, carrying capacity and time were all factors that affected the mutation rate. We also based what we said about the mutation rate on what environment we were working on and why the bugs in a certain environment changed to certain colors. [High-evidence]

Suppositions: High-source/justification dimensions; enrichment-ecological conceptions; Task-comprehensible, plausible, rhetorically compelling, coherent; high-social context

Q: Did your claim change when you saw conflicts in data during your argument? Explain.
GF: My claim did not change; we stuck with it. [Low-certainty]
BH: Yes because we went back and added more information once we talked about it with other students. [High-development]

Suppositions: Mixed certainty and development; Task-comprehensible, plausible; high-social context; dissatisfaction

Q: Where there any patterns in the evidence? Give specific examples if necessary.
GF: Yes, the finches that died had not adapted like the finches that survived and every generation the finches changed so they could survive better. [Low-no evidence]
BH: Yes, because we did the experiments multiple times with different variables and the mutation rate was slow when the bug size was small because the bugs were harder to see so they didn’t need much camouflage. While when we had big bug size, the bugs mutated quickly because they needed to survive before they were killed off since they were so much easier to see. [High-evidence]

Suppositions: Mixed source and justification; BH Task-rhetorically compelling, plausible, coherent; coherent-need-based conception; event/need-based causality;

Q: How is your argument similar to an argument a professional scientist would make?
GF: Because my argument had significant evidence that I was able to back up. I used all my sources and data that I had available to me at the time. [High-certainty]
BH: It’s similar because both use valid data and test our claims with multiple experiments. [High-development]

Suppositions: High certainty/development dimensions; High-self-motivations- self-efficacy, autonomy/self-determination

Q: Where do you find scientific knowledge?
BH: You can find it anywhere, such as the internet, textbooks, your teacher, peers, etc. [High-multiple sources]

Suppositions: High source dimension;

Q: How do you use scientific knowledge? What does learning science or studying science mean to you?
BH: I will use this knowledge later in life in my future career to help me solve problems and diagnose patients and deal with conflicts. It means lot because it is very important for young students to understand how things work and why, especially for the career I want to go into and extending my education. [High-personal relevance]

Suppositions: High-personal relevance, career motivation; source dimension; Task-rhetorically compelling, plausible

Q: Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
GF: Yes because we answered every question completely, provided examples, showed graphs and tables, and we were able to use the evidence we gathered to make a thorough claim. [High-
Certainty/Development]
BH- Yes because I used valid data and research to support my answers and my claim. [Low-did not use specific examples]
Suppositions: Mixed self-motivations; high epistemological beliefs about knowing;

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- I liked it because we were able to decode the data in our own way and get our answers in our own head, it required us to really think about the investigation.
I liked this activity because it was a challenge to us, exposing us to something we don’t do that often, or ever. This added to my knowledge a lot. I became frustrated quite a bit but I overcame that by working with my partner. It was fun and I enjoyed it very much so. [High-autonomy/ self-determination]
BH- I liked this activity a lot because it was hands-on and we had the ability to change whatever we wanted, I liked to be the predator also and the graphs were very helpful because instead of having to search for answers on our own, we got to looks at the graphs right in front of us. This added to my knowledge a lot but yes I did get frustrated at times because I didn’t fully understand something and had to ask questions. It was fun because I liked having the power to change whatever and be the predator and eat lots of bugs. [High autonomy]
Suppositions: High-self-determination/autonomy, need for cognition/intrinsic motivation; high social context

Q- What grade would you give yourself on this activity? Explain.
GF- Honestly I would give myself a 90% to 100% because I think we worked really well together and contributed a lot to this activity. I dedicated myself and opened up to a new thing. [High]
BH- An A because I believe I contributed a decent amount and used all my resources and knowledge. [High]
Suppositions: High-grade motivation, self-efficacy, need for cognition/intrinsic motivation; also recognized that she took a risk; high social context

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:
ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS
Ontology/Epistemology
Student's ontological and epistemological beliefs are coherent, direct- process with varying features, primarily goal and terminal. Reflections reveal alternate conceptions about influence of the environment-purposeful mutation (non-epigenetic, toxic/electromagnetic mutagenic) from influence of environment. Suggests perception that environmental ‘pressures’ cause mutation. Student's written explanations all reflect this ontology and are reflected in her coherent teleological conceptions in narratives. Student shows basis, sometimes faulty understanding of causal mechanism for variations.
Epistemic beliefs are rated overall high (9/11=82%), shows an above average understanding of nature of scientific knowledge. These scores are similar to the average of student self-reported scores on SEB (4.58/5=92%).
Motivations
Results (4/4) on self-motivations indicate; student's written reasoning suggests that she has high self-efficacy and can defend her claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about her work within the group. She displayed persistence when given more autonomy in inquiries. Overall her motivational score average on the motivational survey was 4.58 (92%). Student expressed personal interest and relevance in a career using
science with a score of 3/3 on career and grade motivations. Here overall motivation score was 7/7 or 100%. This is close to the 92% on her SEB surveys.

Mental Model- student's ontological and epistemological framework structure has a consistent network structure with connections between concepts. She shows only minimal enrichment and revision of conceptions through Final Test producing 3/5 evolutionary conceptions (60%) and 4/6 evolutionary conceptions on both the posttest and final test. This student's original pretest had 14 total propositions with 5 scientific propositions. When forced to create connections from her cognitive map structure for her posttest, she produced only 6 scientific propositions from 26 propositions (6/26=23%). Interestingly, her CINS score improved from a score 5 to 13 out of a possible 20. This survey shows enrichment and revision of conceptions and improved conceptual development.

_Brea (ECO+E) Declarative Knowledge from Concept Mapping Propositions_

**Scientific Propositions (Pretest)**
- Populations make up ecosystems
- The reproduction rate influences the size of the population.*
- Changing environments affect differential survival.*
- Carrying capacity is how many species an ecosystem can hold.
- Limiting factors affect the populations.*

_Total Propositions=14; Scientific Propositions =5(36%); 3/5=Evolutionary (60%)_

**Scientific Propositions (Posttest)**
- Changing environments can influence the limiting factors of a habitat.*
- Limiting factors affect differential survival.*
- Changing environments influence ecosystems.
- Individual organisms make up populations.
- Genetic variations mainly affect the individual organisms they occur in.*
- Limiting factors alter the carrying capacity of habitats.*

_Total Propositions= 26; Scientific Propositions=6(23%); 4/6=Evolutionary (67%)_

**Scientific Propositions (Final Test)**
- Reproduction influences the size of a population.*
- Carrying capacity is based off of how many organisms an ecosystem can hold.
- Individual organisms can pass down genetic variations to their offspring.*
- Individual organisms have differential survival in changing environments.*
- Populations make up ecosystems.
- Individual organisms can inherit mutations.*

_Total Propositions=13; Scientific Propositions=6 (46%); 4/6= Evolutionary (67%)

Note: Evolutionary Propositions are noted with *
Appendix C1: Chris

Chris  (ECO)  Explanations for Tasks-Ontological and Epistemological Beliefs

Task 1
As the seasons go by, more and more brown foxes will die off due to predators. This will cause the brown gene to die off and eventually only white foxes will reproduce and pass down white fur genes to their offspring.

Presupposition: Terminal-direct-process ontology
Suppositions: Proximate conception; natural selection concepts-inheritance of variations.

Task 2
It’s basically survival of the fittest. Only the species that were able to blend in and hide from their predators the best will stay alive and pass down there looks. Eventually the main type of species left will be the one who camouflages best with the environment.

Presupposition: Terminal-direct-process ontology
Suppositions: Proximate conception; natural selection concepts-inheritance of variations.

Task 3
As time passed, birds would eat more green beetles than brown beetles. This is because the green beetles were more easily seen in the brown back round. Since over time there are going to be less and less green beetles because of predators eating the prey, less and less green beetles are going to be produced due to a lack of green beetle parents to produce and pass down the green gene.

Presupposition: Terminal-direct-process ontology; genes as entities?
Suppositions: Proximate conception; natural selection concepts-inheritance of variations.

Task 4
In the example of a predator blending in with its environment, a predator will not catch much food if its prey can always see it coming. So over time the non-camouflaged predators would die off due to lack of nutrients and not being able to catch enough food to survive. This would leave only animals that blend in and are able to sneak up on its prey. For an example of a prey camouflaged it is the exact opposite. Over time the prey that didn’t blend in with its environment would be easily spotted and eaten. This would cause only the camouflaged species to survive and populate the environment.

Presupposition: Causal-direct-process ontology
Suppositions: Proximate conception; natural selection concepts-variations and differential survival.

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.
**Pre-Argument Reflection- Finches**

Q: How did limiting factors influence the finch population on Daphne Major?
   Limiting factors decreased finch population because there was extreme lack of resources.

**Ontological/Epistemological Status:**
Enrichment- ecological conceptions.

**Post-Argument Reflection- Finches**

Q: How did limiting factors influence the finch population on Daphne Major?
   When it stopped raining a lot during the Dry 76' to Dry 77' most of the plants started to die leaving less seeds as shown on the graphs in our evidence. The year the finch population began to decrease also had the highest record of heat. This might have affected the finches because they could have become dehydrated due to the lack of rain that season.

**Ontological/Epistemological Status:**
Enrichment/revision- ecological conceptions.

**Pre-Argument Reflection- Bug Hunt**

Q: How do environmental factors influence a bug population over time?
   It can increase or decrease based upon the color of the bug and how camouflaged to that environment the bug is. The environment can increase the bug population if the color of the bug is the same as the environment. The environment can decrease a bug population if the bug is not the same color as the environment which would make it easily seen.

**Ontological/Epistemological Status:**
Enrichment/revision-population conceptions; Assigns purposeful orientation to environment-synthetic model**; natural selection concepts-differential survival.

**Post-Argument Reflection- Bug Hunt**

Q: How do environmental factors influence a bug population over time?
   A bug will live if they are able to be camouflaged with the environment which would make the predators not be able to see the bug. A bug will die if the color of it is not a color which can be camouflaged with a certain environment then the predators will be able to see them which in turn would give them very little chance to survive.

**Ontological/Epistemological Status:**
Enrichment/revision-population conceptions; Assigns intent to camouflaging; natural selection concepts-differential survival;

**Post Argument**

Q: Is your claim scientific? Explain.
   GF- Yes I think my claim is scientific. I answered the focus question in the best way I could using the smartest sounding terms. [Low-no citing of evidence]
   BH- Yes, I would say my claim is scientific. His has to do with things that can be scientifically proven with evidence. [Low- no direct evidence]

**Suppositions:** Low-source/justification dimension; lacks comprehension or motivation

Q: What evidence did you use to support your claim?
   GF- I used data and graphs to support my claim. [Low- no cited evidence]
   BH- We used data collected from the simulation program. Including the size of the bugs compared to the amount killed/survived and the change in color as they adapted to their environment for survival. [High- evidence]

**Suppositions:** Mixed-source/justification dimension; BH Task- comprehensible, plausible, coherent

Q: Did your claim change when you saw conflicts in data during your argument? Explain.
GF- My claim did not change. I revised it a little bit, but the main idea of my claim did not change. [Low-not specific]

BH- No my claim was basically the same during the whole activity. It might have been changed to be worded differently but other than that is was basically the same. [Low]

Suppositions: Low-certainty/development dimension; did not support response

Q- Where there any patterns in the evidence? Give specific examples if necessary.

GF- Yes I saw a few patterns. The seasons there was very low rainfall were also the seasons the seeds were not readily available and the finches were dying off. [High]

BH- Yes, there were a few patterns. Including when we changed the size of the bugs the death rate went up a lot more because the predators were able to see and eat them a lot easier. Also when we lowered the carrying capacity the death rate went down a lot because there were less bugs to eat. [High]

Suppositions: High source/justification dimensions; BH- social context;

Q- How is your argument similar to an argument a professional scientist would make?

GF- I can’t answer that question because I don’t know how a professional scientist would argue. I would guess he would use the data and observations to argue his point as did I. [Low]

BH- It's similar because it is backed up with evidence and facts, which is needed for any argument. It must be proven, backed up with experiments, facts, and explained evidence. [High]

Suppositions: Mixed certainty/development dimension; knowledge internal; Low self-motivations-GF?

Q- Where do you find scientific knowledge?

BH- Look in a trusted resource or test it out for yourself. It must be proven, backed up with experiments, facts, and explained evidence. [High]

Suppositions: High source- individual knowledge generation;

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?

BH- I don't know because I may not even go into a field that uses this information. It means gaining necessary information to better understand the world we live in. I believe it is important. I think learning is gaining knowledge to improve daily life. [Low]

Suppositions: Low personal relevance, not rhetorically compelling

Q- Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?

GF- Yes, I feel like I answered the question to the best of my ability with the data provided to me. [Low- no evidence or reasoning]

BH- Yes, I feel like a gathered enough information to prove and backup my claim. [High]

Suppositions: Mixed self-motivations/ self-efficacy, personal relevance

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- It made it a lot easier to find the answers because it was right there. I don’t really feel anything; I do feel like it added to my knowledge and it was helpful. I was not ever frustrated but I wouldn’t consider this fun. [Low]

BH- I thought it was helpful to use to get information and fun to eat the bugs. I felt I learned a little bit during this activity, including how varying factors and manipulating things can affect environments. It was kind of fun. [High]

Suppositions: Mixed- autonomy/self-determination; low need for cognition/ intrinsic motivation

Q- What grade would you give yourself on this activity? Explain. (grade motivation, self-efficacy, need for cognition/intrinsic motivation)

GF- I would probably give myself a B+ or an A-. I think I did fairly well in explaining myself and providing the needed information to backup my claim. [High]

BH- An A+, because tried my hardest and provided the needed information and answered the questions to the best of my ability. [Low]

Suppositions: Mixed grade/ self-efficacy motivation
Researcher Interpretations:

Ontology/Epistemology

Student's ontological presuppositions seem coherent. Student explanations reveal terminal-direct-process ontology. Student's explanations for tasks show that he can give proximate causation for population interactions and individual variation. Reflection questions did not probe for ultimate causation and no explanations were given.

Epistemic beliefs are rated low overall (5/11=45%), shows a lower level of understanding of nature of scientific knowledge. These scores are dissimilar to the average of student self-reported scores on SEB (4.36/5=87%). Some student responses seemed disingenuous, particularly regarding beliefs about source and justification of knowledge near the beginning of both reflections. This new student to the district does have a propensity to garner attention of peers by being glib.

Motivations

Low rating results (2/4) on self-motivations mirror epistemological responses. Student's written reasoning suggests that he may have low self-efficacy or metacognition, because he cannot defend his claims about meeting the goals of the finch inquiry. He showed low motivations in the modeling inquiry and scored a 1/3 for career and grade motivations. His motivation, reflection-response scores were 3/7 (43%). In comparison, his score average on the motivational survey were lower with 3.15 (63%).

Mental Model- student's ontological and epistemological framework structure has a consistent linear structure with connections between concepts on the pretest and final test. He shows only minimal enrichment and revision of conceptions through final test. On the pretest he constructed 2 scientific propositions of 9 total propositions with ½ evolutionary. Posttest and final tests had 3/4 evolutionary conceptions (75%) with 13 and 11 total propositions respectively. Interestingly, his CINS score improved from a score 6 to 14 out of a possible 20. This survey shows enrichment and revision of conceptions and improved conceptual development.

Chris (ECO) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)

Individual organisms can have genetic variations.*
Genes can have mutations.

Total Propositions=9; Scientific Propositions =2; 1/2=Evolutionary (50%)

Scientific Propositions (Posttest)

Limiting Factors affect the differential survival of organisms.*
Limiting Factors can determine the size of the population.*
Limiting factors can determine the carrying capacity.*
The carrying capacity can change as the environment changes.

Total Propositions =13; Scientific Propositions=4; 3/4=Evolutionary (75%)

Scientific Propositions (Final Test)

Changing environments can affect the carrying capacity.*
Carrying capacity can determine the size of a population.*
Reproduction also determines the size of a population.*
Mutations in genes are also known as genetic variations.
Total Propositions=11; Scientific Propositions=4; 3/4= Evolutionary (75%); 3/11=27%

Note: Evolutionary Propositions are noted with *.

Chris (ECO) Concept Map Structures with Cognitive Map

Pretest-Linear Structure

Cognitive Map

Posttest-Network Structure

Final Test-Linear/Tree
Appendix C1: Don

Don (ECO) Explanations for Tasks-Ontological and Epistemological Beliefs

Task 1
More of the foxes are white now, because the white ones had a better survival rate in the winter because they had better winter camouflage. Since more white foxes survived in the winter there would be more brown foxes around.

Presupposition: suspect terminal-process-ontology; brief description
Suppositions: Description of task- no reasoning for camouflage other than survival; faulty proximate conception.

Task 2
These developed features help those animals survive. They evolved over time until they blended in with their surroundings. This trait helped them be less visible to predators; therefore, bringing their survival rate up. Also animals that have things on their body to look like eyes help distract or scare away predators, which is also very useful to their survival.

Presupposition: causal, direct-process ontology
Suppositions: Teleological conception with proximate causation.

Task 3
The proportions of beetles changed because they adapted to where they live. If more brown beetles were surviving than green ones, than chances are the brown ones would have offspring that are a very similar color to their parents. So since more and more brown beetles would be made as the population of green beetles went downhill there would obviously be more brown alive than green.

Presupposition: Terminal- direct-process ontology
Suppositions: Proximate conception; natural selection concepts-variations, differential survival, inheritance of traits

Task 4
They have developed these features to help survive in an environment they might have trouble surviving in without these features. Over many years they have most likely grown and evolved for better survival. Since they have adapted to help them survive in their environment they would most likely live longer, and be able to have more offspring than similar animals without these features.

Presupposition: Goal-direct-process ontology
Suppositions: Teleological conception with proximate causation; natural selection concepts-variations, differential survival.

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.

Don (ECO) Reflections-Ontological Epistemological and Motivational Status

Pre-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
The environment both helped and harmed the finch population. One way that it positively helped is when it rained a lot there was more food available.
Ontological/Epistemological Status:
Enrichment-ecological conceptions

Post-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Limiting factors affected the population of Daphne Major. I know this because on some years
there were shortages of food, and there were also drops in the population around the same year that food was scarce. Also weather affected the population of the finches. It also supports that when there was more rainfall more seeds were available to be consumed by the finches. Which supports that weather can affect the population of finches whether it’s negatively or positively, by affecting the seed availability.

**Ontological/Epistemological Status:**
Enrichment-ecological conceptions

**Pre-Argument Reflection- Bug Hunt**  
**Q-** How do environmental factors influence a bug population over time?  
It influences the bug population numbers because it could help them blend in or it could make them stick out more. As the environment changes it would also make the bugs change to stay safe from predators. The environment will affect the life of the bugs positively or negatively because a bug can either blend into the environment or stick out.

**Ontological/Epistemological Status:**
Goal, causal-direct-process ontology- teleological conceptions; proximate causation

**Post-Argument Reflection- Bug Hunt**  
**Q-** How do environmental factors influence a bug population over time?  
The survival rate of bugs can be affected by how well they blend in, so if the environment is mostly one color that the bugs would most likely be that color. So if they blended in predators wouldn’t be able to find them. But also if the bugs were a complete different color than the environment than the environment they would be found easier, so the population would go down.

**Ontological/Epistemological Status:**
Enrichment-ecological conceptions, proximate causation; implies need or intention

**Post Arguments**  
**Q-** Is your claim scientific? Explain.  
**GF-** Yes my claim is scientific. I think this because it uses many details to support it. And also uses graphs straight from the Resources. Which help to prove my claim. [Low-no evidence]  
**BH-** Yes I believe my claim is scientific. I think this because research was used to help discover the answer. [Low-no cited evidence]  
**Suppositions:** Low-source/justification dimensions; 'prove' with argumentation

**Q-** What evidence did you use to support your claim?  
**GF-** I used graphs from the research, and also helped explain each graph and how it related to my claim. Each graph showed something different, that added to my claim. [Low- no specific evidence]  
**BH-** I used the graph that I constructed from the bug hunt to help support my claim. [Low]  
**Suppositions:** Low-source/justification dimensions; did not cite specific examples

**Q-** Did your claim change when you saw conflicts in data during your argument? Explain.  
**GF-** No, my claim stayed the same, because even though there were minor changes in the data, most of the time my claim was proven to be true. [Low]  
**BH-** No, I stuck with the same claim throughout the whole project, just added minor things to it. [Low]  
**Suppositions:** Low-certainty/development; did not support or reason for claim; 'right' and 'proven';

**Q-** Where there any patterns in the evidence? Give specific examples if necessary.  
**GF-** Yes, one pattern was that there were more seeds in the wet season than there were in the dry. Another is, that when there were very little seeds one year, the population of the finches dropped. Which also helped prove my claim. [High-evidence]
BH- Yes there were some patterns, like in certain environments it was harder to find bugs because of how well they blended in, also when the bug size was raised, many more bugs were found. [High-evidence]

Suppositions: High source/justification; 'prove' my claim

Q- How is your argument similar to an argument a professional scientist would make?

GF- I think my argument would be similar because the data supports it very well, and if they saw the data they would think something similar to what I had. [Low-right answer]

BH- My argument is similar because they are both using the same evidence to try and answer the same question, and since we have the same evidence I assume our perspectives will be similar. [Low-certainty]

Suppositions: Low-certainty/development dimension; BH Task-certainty low-assumes one right answer; High-self-motivations/ self-efficacy

Q- Where do you find scientific knowledge?

BH- You find scientific knowledge everywhere, because the world is always changing. [Low]

Suppositions: Low source; response too general

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?

(source dimension, plausible, rhetorically compelling, personal relevance)

BH- To help me learn about more things in the future
Learning about science is important, because it’s the study of everything. Science is also needed in a lot of careers now. [High]

Suppositions: Indicates plausibility, but not rhetorically compelling or personally relevant

Q- Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?

GF- I feel that I answered the question fully, I think this because I put every part of the question in my argument, and had the evidence to prove it. [High-cites evidence]

BH- Yes I feel like I answered the question fully. And I hope I met the expectations. [Low]

Suppositions: Mixed self-motivations; High self-efficacy/ rhetoric in GF

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- I feel that I answered the question fully, I think this because I put every part of the question in my answer, and had the evidence to prove it. [repeat]
It was pretty fun, but stressful at some points. Especially at the beginning, because it was hard to get used to looking through the charts and supporting my answers. [High]

BH- I think it was somewhat fun, and the graphs helped me some, but I wasn’t looking at them the whole time. It was kind of stressful at some points, but other than that it was pretty fun. [High]

Suppositions: High self-determination, intrinsic motivation/ need for cognition

Q- What grade would you give yourself on this activity? Explain.

GF- I would give myself an A. I would give myself this because all of my answers and argument were supported well. And I feel like I answered the question to the best of my ability. [High-supported]

BH- I would give myself a low A, or High B. [Low-unsupported]

Suppositions: Mixed self-efficacy, grade motivation.

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:

ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS
Ontology/Epistemology
Student's ontological and epistemological beliefs seem coherent. Student explanations reveal terminal and goal-event process ontology. Student's explanations for tasks show that he can give proximate causation for population interactions and individual variation. He showed improvement in explanation from task week 2 to 4 (Tasks 1 and 3), from just a description to giving a proximate explanation. Reflection responses both pre and post argumentation on bug modeling inquiry showed intentional-event process ontology with teleological conceptions.

Epistemic beliefs are rated extremely low overall (2/11=18%), showing a lower level of understanding of nature of scientific knowledge. These scores are dissimilar to the average of his self-reported scores on SEB (4.09/5=82%). Some student responses seemed disingenuous, particularly regarding beliefs about source and justification of knowledge near the beginning of both reflections. He often gave quick, shortened responses even when encouraged to do his best on all questions.

Motivations
He had interesting rating on self-motivations with a high epistemological beliefs development ratings in ¾ (75%) of his reflection responses. Student's written reasoning suggests that he may have moderately high self-efficacy beliefs. His reflection responses to three questions on career and grade motivations was rated high in 2/3 (67%) responses. He indicated high personal relevance, but lower grade motivations on the bug modeling inquiry. His motivation, reflection-response scores were 5/7 (71%). In comparison, his score average on the motivational survey was lower (2.32=46%).

Mental Model- student's ontological and epistemological framework structure showed development in concept connections on the pretest and final test. His pretest concept map had a more circular structure and his final concept map had more connections and a network structure. He shows enrichment and revision of conceptions through final test. On the pretest he constructed 5 scientific propositions of 13 total propositions with 4/5 evolutionary conceptions. Of the 16 created propositions to his cognitive map on the posttest, he only constructed 2 scientific propositions (2/16=13%). (This result mirrors Ann's statistics on her posttest). He constructed 6 scientific propositions of the 18 (33%) total propositions created. Of the 6 scientific propositions 100% were evolutionary. His CINS score improved from a score 8 to 12 out of a possible 20. This survey shows enrichment and revision of conceptions and improved conceptual development.

Note motivational level in this class low- last period of the day...

Don (ECO) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Individual organisms have their genes passed down by heredity.*
Genes are passed down from parents, which is heredity.*
A changing environment can cause differential survival.*
Ecosystems can be changing environments.
Populations can change because of an ecosystem.*

Total Propositions=13; Scientific Propositions =5; 4=Evolutionary (80%)

Scientific Propositions (Posttest)
Populations live in an ecosystem
Populations can be affected by genetic variations.*

Total Propositions =16; Scientific Propositions=2; 1/2=Evolutionary (50%)

Scientific Propositions (Final Test)
Genes are passed down from parents, which is heredity.*
Mutations can be passed down from heredity.*
Changing environments can be a limiting factor.*
Ecosystems can affect how many organisms live or die in a population.*
Changing environments can hurt or help a population.*
Genetic variations occur in individual organisms.*

Total Propositions=18; Scientific Propositions=6; 6/6 = Evolutionary (100%)
Note: Evolutionary Propositions are noted with *.

Don (ECO) Concept Map Structures with Cognitive Map

Pretest-Circular Structure

Cognitive Map

Posttest-Network Structure

Final Test-Network Structure
Appendix C1: Kevin

Kevin (ECO)  Explanations for Tasks-Ontological and Epistemological Beliefs

Task 1
I believe that the white fox population will be denser then the brown fox population because the white fox population could catch more food in the winter. Even if the brown fox population caught enough food it would still not reproduce as much. The population has changed because now there are more white fox then the brown fox because food was not a limiting factor any more for them.

Presupposition:  Terminal-direct-process ontology
Suppositions:  Proximate conception; enrichment-ecological conceptions

Task 2
Over time they adapted to increase survival rates within the species. The ones that were born, and blended in survived and those are the ones that reproduced. The ones that looked different died off and didn’t reproduce. I believe this is a good example of natural selection. The mantids that were born green and not red survived and those are the ones that reproduced to more green mantids. That is how a population becomes diverse from others of the same species.

Presupposition:  Terminal-direct-process ontology
Suppositions:  Proximate conception; enrichment-ecological conceptions; natural selection concepts- variation, differential survival, inheritance of variations; used classroom examples; first declaration- more teleological, but not reflective of overall conceptions

Task 3
We will see that most of the brown beetles have reproduced and many of the green ones have gone and not reproduced to carry on the green color in the ecosystem. This is because the brown mutation was useful in the survival of the beetles and that this is what carried on and the ones that were not useful died off like the green ones. If the environment changed like the grass was a bit greener or there were more leaves on the trees then it could have possibly been the other way around and the brown ones died off.

Presupposition:  Terminal-direct-process ontology
Suppositions:  Evolutionary conception- population change through time; enrichment-ecological conceptions; natural selection concepts- variation, differential survival; inheritance of variations

Task 4
These animals have developed this over time to help adapt to their environment. For example the polar bears could have originated from regular black bears and over time the ones that were born lighter in color survived because it could find food and over a very long period of time the polar bears became a lighter and lighter shade of color each generation and that is how this occurred over time.

Presupposition:  Terminal-direct-process ontology
Suppositions:  Evolutionary conception- population changes through time; proximate causation; natural selection concepts- variation, differential survival; inheritance of variations

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.
Pre-Argument Reflection- Finches
Q- How did limiting factors influence the finch population on Daphne Major?
   Limiting factors such as water availability or food availability limited the number of finches on Daphne Major because there were no resources to support the population. The finches that were well developed survived the climate event and those finches reproduced.
   Ontological/Epistemological Status:
   Enrichment- ecological conceptions; proximate causation; natural selection concepts- variation, differential survival; inheritance of variations

Post-Argument Reflection- Finches
Q- How did limiting factors influence the finch population on Daphne Major?
   The three seasons where there was very little rain fall for a whole year drastically reduced the amount seeds produced by plants also there was much less water on the island. That meant the finches had low resources on the island and many of the finches died. Evidence showed that the limiting factor of the rain fall limits the amount of finches that can live in a given area. The less rain fall produced less seeds and the finches died off.
   Ontological/Epistemological Status:
   Enrichment- ecological conceptions; proximate causation; natural selection concepts- variation, differential survival

Pre-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
   It changed the bug population so that they were better hidden in the certain environment. In example if there was a red field, then the bugs that were red or a darker shade survived and reproduced the ones that didn't fit in, got killed and did not reproduce. The better that the bugs could blend in the more that they survived so there was less change in the numbers of bugs.
   Ontological/Epistemological Status:
   Goal-direct-process ontology; enrichment- ecological conceptions; proximate causation; natural selection concepts- variation, differential survival; synthetic model

Post-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
   If the bug was suited for the environment it had a better chance of surviving and reproducing. The predators have a harder time catching the bugs that blended in to their environment so those bugs survived. I think this is a good example of natural selection. The bugs that were born and blended in with the surrounding environment survived to reproduce and carry on that mutation and the offspring of those bugs had slight variation from the parents and blended in even better survived to the next generation until the perfect camouflage in the certain environment.
   Ontological/Epistemological Status:
   Terminal-direct-process ontology- 'perfect'; evolutionary conceptions; proximate causation; natural selection concepts- variation, differential survival, inheritance of variations; ontology seems coherent, plausible explanation, committed.

Post Argument
Q- Is your claim scientific? Explain.
   GF- Yes, I think that the claim I gave is scientific because I backed up my claim with evidence.
   [High]
   BH- Yes I believe my claim is scientific, it states an observation and then is backed up with evidence. [High]
   Suppositions: High-source/justification; Tasks-comprehensible, coherent

Q- What evidence did you use to support your claim?
   GF- I used graphs to support my claim and showed what the graphs meant and show why a lot of finches died. [Low-not specific]
   BH- I used evidence from the modeling activity to support my claim. [Low-not specific]
Suppositions: Low-source/justification dimension, responses lack specific detail about evidence; Tasks-plausible, comprehensible

Q-Did your claim change when you saw conflicts in data during your argument? Explain.
GF- No, I looked at the evidence before I made my claim so that I would have good evidence to support my claim.[High]
BH- Yes, this modeling activity changed my view on animals adapt to their environment how only the ones that were suited for the environment survived and the other died.[High]

Suppositions: High-certainty/development dimension; Tasks-comprehensible, plausible; motivation-dissatisfaction with conceptions

Q- Where there any patterns in the evidence? Give specific examples if necessary.
GF- Yes there were patterns in the evidence such as in 1977 many of the finches died off from what look like a drought. This pattern was across most of the finches.[High]
BH- Yes there were patterns in the evidence, you could see that many of the bugs that blended in with the environment were the ones that reproduced to make more bugs that blended in with their environment. [Low-inference from evidence]

Suppositions: Mixed-source/justification dimension;

Q- How is your argument similar to an argument a professional scientist would make? (source/Justification dimensions, need for cognition/intrinsic motivation, self-determination)
GF- My argument is similar to that of a professional scientist because I made a claim, supported it with evidence and made justification to why I believe I am correct. [High]
BH- My argument is similar to an argument a scientists would make because I made a claim and supported it with evidence then justified my claim to the evidence. [High]

Suppositions: High-certainty/development dimension; high-self-efficacy

Q- Where do you find scientific knowledge?
BH- You find scientific knowledge everywhere. [Low]

Suppositions: Low-source dimension, general-vague response; low self-motivation-not committed

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
BH- I will probably use this knowledge to pass a test.
Yes I believe that learning about the world is important. Years ago people though that there was no way that there could be “aliens” but in modern times we have figured out many things. For example the Goldilocks theory says that there is a very good percentage that there are other organisms on different planets. [High]

Suppositions: High source dimension; Task-gave example, rhetorically compelling, plausible

Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
GF- I believe that given the time to do the work I put in a fair amount of evidence for the investigative question. I could have probably given more evidence to support the claim. [High]
BH- Yes, I believe that I have answer the questions outlined in the investigative question. I did the modeling activity then made a claim and supported it with evidence then justified my claim to my evidence. [High]

Suppositions: High self-motivations, self-efficacy, autonomy/self-determination; task-plausible, rhetorically compelling

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?
GF- I like it because you can find the answers at your own pace and support you answers with the data.
I don’t think this was very fun because it was school work and no one like school work. But it was better than most things because you could go at your own pace. This added to my knowledge about finches and the Galapagos. [High]

BH- I really wouldn't consider it fun but it was better than most things like a big guided reading. Yes this added to my knowledge of how a species changes over time. I enjoyed this type of activity, you got to choose what happened in the activity. The graphs were helpful because you got to see what changed in the environment according to how you changed it. [High]

Suppositions: High self-motivations, autonomy/self-determination, self-efficacy, need for cognition/intrinsic motivation; BH Task plausible, comprehensible, rhetorically compelling

Q- What grade would you give yourself on this activity? Explain.
GF- I would give myself a 91%. I believe I should earn this because I gave good evidence and supported it well. [High]
BH- I would give myself about a 75-80% because it was a bit rushed. [Low]

Suppositions: Mixed motivations, self-efficacy, need for cognition/intrinsic motivation, grade motivation

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:
ONTOGONY/EPISTEMOLOGY/MOTIVATIONS
Ontology/Epistemology
Student's ontological and epistemological beliefs seem to be coherent, direct-process ontology with mostly terminal features. Reflections revealed terminal-event teleological conceptions-implies individual adaptation. Did not give teleological narratives on tasks. Student's written explanations all reflect this ontology and are reflected in his consistent proximate causation reasoning in narratives. Student explanations for tasks show understanding of mechanism for variations and differential survival, and population change with time.

Epistemic beliefs are rated overall relatively high (7/11=64%), shows satisfactory understanding of nature of scientific knowledge. These scores are lower than the self-reported final score on SEB (4.29/5=86%).

Motivations
Results (4/4) on self-motivations indicate; student's written reasoning suggests that he has high self-efficacy and can defend his claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about his work. Response to personal relevancy score was high on career and grade motivations (2/3). He reported that he liked both inquiries and enjoyed autonomy, but felt he had rushed on the bug modeling inquiry. Overall his motivational score on the post survey was lower mean loss (-0.30) with an average score of 4.06 (81%). This score is similar to the reflection scores of 86% (4/4+2/3=6/7).

Mental Model- Student's ontological and epistemological final framework structure was network like with more connections between concepts, when compared to his pretest, circular/tree structure. There was improvement in the number (2) of declarative, evolutionary conceptions from the pretest to final test. He shows enrichment and revision of conceptions through final test. Four of 6 scientific propositions were evolutionary on the pretest, 4/4(100%) evolutionary conceptions on the posttest, and 6/9 (67%). His CINS score improved from pretest to posttest with a score 9 to 11 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development.
Kevin (ECO) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Reproduction gives hereditary traits.*
Reproduction increases population in the ecosystems.*
Limiting factors decreases the population growth.*
The population cannot expand larger than the carrying capacity.*
Ecosystems contain different populations.
Populations are made up of individual organisms.

Total Propositions=11; Scientific Propositions =6; 4/6=Evolutionary (67%)  

Scientific Propositions (Posttest)
Genes are passed on when an organism reproduces*.
Reproduction causes genetic variation.*
Reproduction increases the population.*
Limiting factors affect the size of the population.*

Total Propositions =18;Scientific Propositions=4; 4/4=Evolutionary (100%)  

Scientific Propositions (Final Test)
Population can’t exceed the carrying capacity.*
Populations have limiting factors.*
Differential Survival is the ability for individual organisms to survive.*
Populations increase with reproduction.*
Populations are made up of individual organisms.
Populations make up ecosystems.
Genetic variations occur in individual organisms.*
Changing environments can be a limiting factor.*
Ecosystems have many different populations.

Total Propositions=20;Scientific Propositions=9; 6/9= Evolutionary (67%); 6/20=30%

Note: Evolutionary Propositions are noted with *
Kevin (ECO) Concept Map Structures with Cognitive Map

Pretest-Circular/Hub Structure

Cognitive Map

Posttest-Network Structure

Final Test-Network Structure
Appendix C1: Lisa

*Lisa (ECO) Explanations for Tasks-Ontological and Epistemological Beliefs*

**Task 1**
You will mostly find the white foxes because in the wintery climate it is a lot easier for the prey to detect their predator if it is brown because they *stick out against the white wintery climate*. The *population of the brown foxes would then decrease* because it would be both harder for them to find food, and easier for them to be seen by hunters because they stick out so much better.

*Presupposition:* Terminal-direct-process ontology  
*Suppositions:* Proximate conception; enrichment-ecological conceptions.

**Task 2**
The animals did not develop these features as much as they became more apparent. The *features were there before*, but as the other types of their species without the adaptations that they had began to die off, the *ones with the adaptations continued to live and reproduce* creating more of their kind with these distinct features. They needed these things *in order to survive in their environment*, so they came with time.

*Presupposition:* Goal, terminal-direct-process ontology  
*Suppositions:* Teleological conception with evolutionary (past processes) and proximate causation; natural selection concepts- variation and adaptation, change over time.

**Task 3**
The proportions of the beetles living in the forest has changed *due to the visibility* of the green beetles. The beetles being green, were easier for predators to see. They slowly die off after time, because *they can no longer reproduce* because of such small amounts that are still alive. This leaves the brown beetles who aren’t caught to reproduce because there are so many not caught, so they continue to flourish.

*Presupposition:* Terminal-direct-process ontology  
*Suppositions:* Proximate conception; enrichment-ecological conceptions; natural selection concepts of variation, differential survival, inheritance

**Task 4**
The animals have not determined these features for themselves. These *features are in the genes that they possess*. The genes *give them their color and the shape* that they have which help them to survive. The animal itself can’t change the color it is, or the way that its body blends into their habitat, the animals genes do.

*Presupposition:* Causal, terminal-direct-process ontology  
*Suppositions:* Proximate conception- describing individual variation; lacking explanation of causal mechanism for population change

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.

*Lisa (ECO) Reflections-Ontological Epistemological and Motivational Status*

**Pre-Argument Reflection- Finches**
**Q-How did limiting factors influence the finch population on Daphne Major?**

Limiting factors such as *water availability* or *food availability* limited the number of finches on Daphne Major because there were *no resources* to support the population. The finches that were *well developed survived the climate event and those finches reproduced*. [repeat]

*Ontological/Epistemological Status:*
Enrichment/revision-ecological conceptions; proximate causation; natural selection concepts-variation, differential survival; inheritance of variations

Post-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Evidence showed that the limiting factor of the rain fall limits the amount of finches that can live in a given area. The less rain fall produced less seeds and the finches died off.
Ontological/Epistemological Status:
Enrichment/revision-ecological conceptions; explanation of causality

Pre-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
The environment can make the bug population number higher or lower based on the color and size of the bugs. The population of a bug is decided by their ability to blend in their surroundings.
Ontological/Epistemological Status:
Goal-intentional direct-process ontology; teleological explanation; phenotype seems determined.

Post-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
Over time the bug population starts to evolve and adapt to its environment. Predation and the environment determine whether a bug lives or dies because it constantly changes when the bug doesn’t. A bug isn’t easily spotted and caught when the have the same type of color as their surroundings.
Ontological/Epistemological Status:
Enrichment/revision-ecological conceptions; Causal mechanistic explanation; general use of terms ‘evolve’ and ‘adapt’.

Post Argument
Q- Is your claim scientific? Explain.
GF- Yes, my claim is scientific. Limiting factors such as water availability limited the number of finches on Daphne Major because there were no resources to support the population. [High-gave evidence/reasoning]
BH- Yes, it is scientific because it includes scientific data collected from the model.[Low-no link to claim]
Suppositions: Mixed source/justification dimension; GF task- comprehensible, plausible, coherent; Enrichment- ecological conceptions

Q- What evidence did you use to support your claim?
GF- The three seasons where there was very little rain fall was about 25cm of water for a whole year drastically reduced the amount of seeds produced by plants. Also there was much less water on the island. That meant the finches had low resources on the island and many of the finches died. [High]
BH- I used the evidence of the number of bugs caught in the different environments, and why some were left after I tried to catch some. The bugs that were left blended into their environments which supported my claim that the population is decided by the environment in which it lives. [High]

Suppositions: High-source/justification dimension; combines all limiting factors to ‘environment’- alternate conception; conceptions comprehensible, plausible, coherent

Q-Did your claim change when you saw conflicts in data during your argument? Explain.
GF- No, it was the exact same as before, because the data proved the claim. [Low]
BH- No my claim did not change, it stayed the same because my data determined my claim from the beginning, and the data consistently supported my original claim. [High-supported]
Suppositions: Mixed-certainty/development dimensions; ‘proved’, inconclusive-coherent; High self-efficacy motivation
Q- Where there any patterns in the evidence? Give specific examples if necessary.
   GF- I saw that the more seeds and rainfall there was, the more finches survived. [High]
   BH- There is a pattern that the color of the surroundings. [Low-no evidence/inference]
   Suppositions: Mixed-source/justification dimension; no reasoning for certainty of knowing

Q- How is your argument similar to an argument a professional scientist would make?
   GF- My claim came from scientific evidence, the same that a professional scientist’s would.
   [High]
   BH- My argument is similar because it is based on scientific evidence, the same as a professor’s would be. [High]
   Suppositions: High certainty/development dimension; considers her evidence ‘scientific’; High-self-motivation, self-efficacy

Q- Where do you find scientific knowledge?
   BH- You find scientific knowledge in experiments. [Low]
   Suppositions: Low source/certainty-indicates scientific knowledge/knowing comes only from experimentation

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
   BH- I will use this knowledge to help me in life. I think that learning science is important because you need to know what is happening in the world around you. Learning means taking something taught to you and being able to apply it to things that actually happen to you, not just memorize things in a book. [High]
   Suppositions: Shows high personal relevance

Q- Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
   GF- I feel that I answered the investigative question fully, because I gave examples and explained my reasoning. [High- argument]
   BH- Yes I feel that I answered the investigative question fully and me the goals in this activity because I did the best that I could during the argument. [Low]
   Suppositions: Mixed-self-motivations, self-efficacy, autonomy

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?
   GF- I found that it was different at first but then became very easy to use data to find answers rather than a paragraph to read. [High]
I liked this activity a lot more than a lot of the other assignments that we do because I felt like it was actually challenging us rather than an easy guided reading assignment.
BH- I didn’t like the computer modeling activity because it hurt my eyes to look for the little bugs, but I did like how it portrayed how things work in nature.
I think this helped add to my knowledge about how bugs can change to fit their surroundings, but I didn’t find it fun because it hurt my eyes because of the computer screen. [High]
Suppositions: Mixed self-motivations, autonomy, intrinsic motivation/need for cognition

Q- What grade would you give yourself on this activity? Explain. (grade motivation, self-efficacy, need for cognition/intrinsic motivation)
   GF- I would give myself an A- because I feel like I could’ve been more clear on some of my answers, but it was good overall. [High]
   BH- I would give myself an A because I tried really hard and think that I did a good job on this assignment. [Low]
   Suppositions: Low- intrinsic motivation, self-efficacy; did not argue or substantiate earning grade
Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:
ONTOMOLOGY/EPISTEMOLOGY/MOTIVATIONS
Ontology/Epistemology
Student's direct-process seems coherent. Student explanations reveal terminal and goal-direct process ontology. Student's explanations for tasks show proximate causation for population interactions and individual variation. She showed improvement in explanation from task week 2 to 4 (Tasks2 and 4), from a teleological explanation to giving a proximate explanation. Reflection responses both pre and post argumentation on bug modeling inquiry showed intentional-event process ontology with teleological conceptions. Interestingly this is similar to Don and other students, particularly because this question is basically the same question used in the finch inquiry, with the exception of the use 'over time'.

Epistemic beliefs are rated moderately high overall (7/11=64%), showing a more average level of understanding of nature of scientific knowledge. These scores are dissimilar to the average of his self-reported scores on SEB (4.46/5=89%). Student responses that required application of argumentation to support her own work were rated low. She did not fully support her responses with evidence and reasoning.

Motivations
Student had a moderately high rating on self-motivations with a high beliefs development ratings in ¾ (75%) of her reflection responses. Student's written reasoning suggests that she may have moderate self-efficacy beliefs and self-determination. Her reflection responses to three questions on career and grade motivations was rated low (0/3=0%). She indicated no real personal relevance, and gave only generalized, more automated responses. Once again, she could not give argument for her grades. She may have lower self-efficacy or metacognition. Her overall motivation, reflection-response scores were 3/7 (43%). This score was among the lowest in both classes. In comparison, her score average on the motivational survey was low (2.86=57%). These scores are very similar and reflect overall lower motivations. Also notable was the lack of any reference to her work in a group or within a social context. She is the only participant where this was clearly evident.

Mental Model- student's ontological and epistemological framework structure showed similar network development in concept connections on the pretest and final test. She shows only moderate enrichment and revision of conceptions through final test. On the pretests he constructed 3 scientific propositions of 9 (33%) total propositions with 3/3 evolutionary conceptions. Of the 18 created propositions to match her cognitive map on the posttest, she only constructed 3 scientific propositions (3/18=17%). (This result mirrors other students' statistics on posttests). She constructed 4 scientific propositions of the 17 (23%) total propositions created on the final test. Of the 4 scientific propositions 100% were evolutionary. Her CINS score improved from a score 7 to 10 out of a possible 20. This survey shows enrichment and revision of conceptions and improved conceptual development.

Note motivational level in this class low-most of the time last period of the day...?
Lisa (ECO)  Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Changing environments cause different survival in individual organisms.*
Individual organisms have genetic variations.*
Genes can have mutations.*

Total Propositions=9; Scientific Propositions =3; 3=Evolutionary (100%)

Scientific Propositions (Posttest)
Changing environments effect differential survival.*
Individual organisms make up populations.
Genes can have mutations in them.

Total Propositions =18; Scientific Propositions=3; 1/3=Evolutionary (33%)

Scientific Propositions (Final Test)
Individual organisms have genetic variations.*
Limiting factors determine carrying capacity.*
Differential survival is determined by limiting factors.*
Genes are passed on through heredity.*

Total Propositions=17; Scientific Propositions=4; 4/4= Evolutionary (100%); 4/17=24%
Note: Evolutionary Propositions are noted with *
Lisa (ECO)  Concept Map Structures with Cognitive Map

Pretest-Network Structure

Cognitive Map

Posttest-Network Structure

Final Test-Network Structure
Appendix C1: Mike

**Mike (ECO) Explanations for Tasks-Ontological and Epistemological Beliefs**

**Task 1**
White Foxes were not able to be seen by prey so the prey had no chance to get away from the foxes, while the brown foxes were able to be easily seen so their prey could react and get away. Since the Brown foxes were seen by prey the *White Foxes would have more opportunities to eat since they were hidden in the environment*. So Brown Foxes would die off to a lack of food supply. So White Foxes would be more found in the fox population by the end of the winter because they were able to catch more foxes than Brown foxes because the *brown foxes were seen by prey during the winter* leaving the brown foxes less opportunities to catch food. So in conclusion the Brown Foxes would not eat as much through an entire winter as White Foxes because the Brown Foxes Would be easily spotted. This would end up *having the brown foxes start to die off* while the White Fox population would not be effected.

**Presupposition:** Terminal-sequential -direct-process ontology

**Suppositions:** Proximate conception; enrichment/revision-ecological conceptions; natural selection concepts- variation, differential survival.

**Task 2**
They developed these features because the survivors of the environments would reproduce and then their offspring would have similar genes allowing the offspring to be able to hide in an environment. So over many of years these animals survivors of the past were able to reproduce now leaving a lot all adapted animals that can survive in these different environments. So the populations have developed these features after the *survivors passed the genes down over the years*.

**Presupposition:** Goal, terminal-direct-process ontology

**Suppositions:** Proximate conception- no explanation of how populations have changed over time; natural selection concepts-adaptations, differential survival, inheritance; potential teleological conceptions- 'to be able to', but continued explanation reveals otherwise

**Task 3**
The proportions have changed to mostly be consisted of Brown beetles because the *survivors of the birds would reproduce leaving offspring where they could hide themselves* while the green beetle would not survive over time. The reason for this is because Beetles are found on trees and the birds were able to find the green beetles more easily than the brown beetles. So over the beetles of the first survivors would reproduce, creating offspring that would *be able to hide from the birds where the green beetle would eventually be wiped out over time* because they were not able to hide themselves in the beginning.

**Presupposition:** Goal, terminal-direct-process ontology

**Suppositions:** Teleological conception with evolutionary conceptions of population change over time; natural selection concepts-adaptations, differential survival, inheritance.

**Task 4**
They have developed these traits because *over time the survivors in the environment would reproduce, creating offspring that would be hidden* in the environment. Evidence of this is the fact that animals like the polar bears are hidden in their environment and insects can look like leaves. So as the *survivors of the environment began to produce offspring with similar genes to them*(surviving parents) the children would survive as well. So over time as this process of the *survivors having offspring like them*, creating the animal as a whole to develop these surviving features over time.

**Presupposition:** Terminal-direct-process ontology

**Suppositions:** Proximate conception; no declarations of population change over time; natural selection concepts-inheritance of adaptations, differential survival.

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.
Mike (ECO)  Reflections-Ontological Epistemological and Motivational Status

Pre-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Limiting factors decreased finch population because there was extreme lack of resources. The 3 seasons when there was very little to no rainfall, these are the same seasons where the finch population seemed to decrease more rapidly. This rainfall shortage would cause dry environments and low plant population and low food shortage. During the Dry’76’ and Dry ‘77’ many finches were having trouble finding seeds to eat. Some would go long periods of time without finding food.
Ontological/Epistemological Status:
Enrichment-ecological conceptions

Post-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
The tribulus seeds were the most plentiful but also have the largest and hardest shell leaving only birds with strong and long beaks to be able to survive. The year the finch population began to decrease also had the highest record of heat. This might have affected the finches because they could have become dehydrated due to the lack of rain that season. So limiting factors decreased the finch population.
Ontological/Epistemological Status:
Enrichment-ecological conceptions; natural selection concepts-variations, differential survival

Pre-Argument Reflection- Bug Hunt
Q- How do environmental factors influence bug population over time?
It can increase or decrease based upon the color of the bug and how camouflaged to that environment the bug is. The environment can increase the bug population if the color of the bug is the same as the environment. The environment can decrease a bug population if the bug is not the same color as the environment which would make it easily seen.
Ontological/Epistemological Status:
Enrichment-ecological conceptions; assumption-only the physical environment itself (not limiting factors, like predation) no discussion of specific environmental limiting factors; intentional quality?

Post-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
The environment would influence the population to look more like the environment because over time the survivors of an environment would pass down their genes to their offspring making them look like the environment. So the bugs would look more like the environment over time. So the environments influence the bug population because the survivors in each of the environments will pass down the same genes to their offspring so that they can hide in the certain environments from predators.
Ontological/Epistemological Status:
Goal-sequential direct-process ontology; proximate causation; natural selection concepts-variations, differential survival; ontology seems coherent, plausible explanation, committed.

Post Argument
Q- Is your claim scientific? Explain.
GF- I believe so because we took the question and added on to it by telling what caused the finch population on Daphne Major and that was a lack of resources. [Low]
BH- Yes our claim is scientific because we explained how the environment will influence the bugs population. [Low]
Suppositions: Low-source/justification dimension; no link to evidence support of claim; Tasks comprehensible, plausible, coherent
Q- What evidence did you use to support your claim?
GF - We used data to see how and when the finch population began to decline. We then used seed availability for Cactus, Chamaesyce, Portulaca, and Tribulus seeds to see if they declined while the finch population was declining. We also used average rainfall to show that the amount of rainfall corresponds with the finch population. We also used temperature to show the correspondence between the temperature and the amount of rainfall for a certain season. [High] BH - We used evidence showing how much the bug population changed appearance from what they started out to the survivors being completely different looking so they could hide from predators. [High] 

Suppositions: High-source/justification dimension; Q-Did your claim change when you saw conflicts in data during your argument? Explain.

GF - A little bit because our claim started out pretty general and got a little more specific as to why we said the population had decreased but what we saw evidence wise didn’t conflict an awful lot with our claim in the very beginning. [High]
BH - Yes our claim changed from us thinking that the bugs just changed over time to realizing that the environment was the influence for why the bug population changed over time. We realized that bugs just didn’t just change but that the survivors were the ones able to hide from the predators and when the survivors reproduced then they would be able to hide from the predators just like their parents had. [High]

Suppositions: High-certainty/development dimension; also BH-students realized more than 1 explanation for population changes- genetic drift-dissatisfaction; Tasks were comprehensible, plausible, coherent; high social context

Q- Where there any patterns in the evidence? Give specific examples if necessary.

GF - The patterns in our evidence was astounding because the Seeds, Finch Population, and average rainfall all declined at the same period of seasons. (Between Dry ’76’ and Dry ’77’) [High]
BH - There were some patterns in our evidence. The patterns were how the bugs all seemed to change in all the environments in order to survive. Like how by the end they all seemed to blend in to their environments by the end of the trial. [High]

Suppositions: High-source/justification dimension; shows teleology

Q- How is your argument similar to an argument a professional scientist would make?

GF - Maybe not as strong but I feel that we had a good claim and sufficient evidence and that we linked our claim to our evidence very well. So I feel like it might not be as good because that is their job but I feel like we were pretty close. [High]
BH - I believe it is very similar because I feel like we had a solid claim answering the focus question. I feel we had solid and sufficient evidence. I also feel like our justification was sufficient and was very strong in how well we linked the claim to the evidence. So I feel like their probably were some striking similarities to a professional scientists. [High]

Suppositions: High-certainty/development; lower-source/ self-efficacy-'not as good or strong'; high social context-motivation

Q- Where do you find scientific knowledge?

BH - You find scientific knowledge in the experiments you do and how much you study science and science data. That scientific knowledge is found and discovered by gathering data and understanding the evidence/data found by doing experiments or computer modeling. [High]

Suppositions: High-source dimension; implies individual generation of knowledge

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?

BH - I will use this knowledge that I have gained as just more information that I have gained throughout my schooling. [Low-general]

It means a little to me but I’m not the most interested person when it comes to science. It is just more knowledge to me but my career choice more than likely so to me it just more knowledge that I can have to absorb. Learning means gaining and or receiving knowledge.

Suppositions: Low personal relevance; does not give specific ways he will apply knowledge gained; not rhetorically compelling
Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?

GF- I feel like we did answer the investigative question fully because I feel that in the argument we were able to show that limiting factors affected the finch population in a certain way. [High]

BH- I do feel like I did answer the question fully because I explained why the environment influences the bug populations. Also I believe that I met the goals of the computer modeling activity because I answered all of the questions and found all the data and most important of all I feel like I sufficiently answered the focus question. [High]

Suppositions: High-self-efficacy; GF task- high social context

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- I thought it was easier than reading a long paper because I was able to interpret the data easily which allowed me to understand what was going on, on the island. So yes I enjoyed using data to discover the answers. [High]

This added to my knowledge a lot because I got a lot more data I feel from this then that packet we got on the Galapagos finches. I wasn’t really frustrated about the website but I was just a little frustrated with trying to work with someone I never had before. I thought it was a pretty fun getting to look at more charts instead of packets on these finches. [High]

BH- I liked to manipulate the bug size because it made it really easy as the predator to catch the bugs. The graphs were really helpful when it came to gathering good and sufficient evidence for our scientific argument.

I felt like we learned a lot throughout this project. I feel like this added quite a bit to my knowledge and how I on how to use computer modeling. I was somewhat frustrated with the modeling but I got through it and feel that we put a good project together. [High]

Suppositions: High autonomy/self-determination, need for cognition/intrinsic motivation; high social context in GF-indicates a bit of unease working with a new partner.

Q- What grade would you give yourself on this activity? Explain.

GF- I would give myself and our group an A. I feel this way because we put a lot of work into finding all the questions and then finding and concluding on what we saw in the evidence. I feel we deserve an A for all of the work and I feel that we were able to specifically link our evidence to our claim. [High]

BH- I would give myself an A for the project because I feel that we answered the questions to the fullest extent and I feel that our claim was solid by saying the environment did in fact influence the population of the bugs. Also our evidence supported our claim showing the color differences from beginning to end. I also feel like our justification was good and was in fact able to link our claim to the evidence. [High]

Suppositions: High-self-efficacy, grade motivation, need for cognition

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006)

Researcher Interpretations:

ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS

Ontology/Epistemology

Student's ontological presuppositions seem to be coherent, event processes with mostly terminal features. Post-argument reflections revealed goal-event-sequential, direct-process ontology; teleological conceptions-implies individual abilities find environments to hide in. Three of four explanations for tasks were proximate with one (Task 3) with teleological conceptions.
Student’s written explanations reflect consistent proximate causation reasoning in narratives. Student explanations for tasks show basic understanding of mechanism for variations and differential survival.

Epistemic beliefs are rated overall relatively high (8/11=73%), shows satisfactory understanding of nature of scientific knowledge. These scores are similar to, but lower than, the self-reported final score on SEB (4.07/5=82%).

Motivations
Results (4/4) on self-motivations indicate; student’s written reasoning suggests that he has high self-efficacy and can defend his claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about his work. Response probing for personal relevancy score was rated low, but his grade motivations were high. Overall his score for career and grade motivations was 2/3(67%) He reported that he liked both inquiries and enjoyed autonomy and social context. Overall his motivational score did not change from pre to posttest (4.07=82%). This score is very similar to the reflection scores of 86% (4/4+2/3=6/7).

Mental Model- Student's ontological and epistemological final framework structure showed more connections between concepts, from his pretest, circular/tree structure to final test, network structure. There was improvement in the number (4) of declarative, evolutionary conceptions from the pretest to final test. He shows enrichment and revision of conceptions through final test. Five of 6 scientific propositions were evolutionary on the pretest, 11/13(85%) evolutionary conceptions on the posttest, and 10/13 (77%). His CINS score improved from pretest to posttest with a score 10 to 13 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development.
Mike (ECO) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Limiting factors decrease populations.*
Populations can't expand larger than the carrying capacity.*
Populations are made up of individual organisms.*
Ecosystems contain different populations.
Reproduction increases the populations in ecosystems.*
In ecosystems some organisms have differential survival.*

Total Propositions=12; Scientific Propositions =6; 5/6=Evolutionary (83%)

Scientific Propositions (Posttest)
Changing environments will effect ecosystem.
Genes determine the characteristics of individual organisms.
Genes are passed to offspring through reproduction.*
Reproduction can make organisms populations reach their carrying capacity.*
Limiting factors can limit the chances of some populations from reaching carry capacity.*
Carrying capacity once reached only the survivors with certain traits will survive in differential survival.*
Changing environments causes organisms in populations to have differential survival.*
Populations over generations will adapt to changing environments.*
Carrying capacity could be reached in some populations in changing environments.*
Mutations can occur in individuals within populations.*
Mutations will occur in populations over time in changing environments.*
Reproduction will cause variances over time in populations.*
Limiting factors can reduce the amount of organisms within populations.*

Total Propositions =22; Scientific Propositions=13; 11/13=Evolutionary (85%)

Scientific Propositions (Final Test)
Reproduction increases the number of organisms in populations.*
Mutations can change genes.*
Reproduction can make some populations eventually reach carrying capacity.*
Changing environments will affect ecosystems.
Ecosystems contain different populations.
Genes determine the characteristics of individual organisms.*
Populations are made up of individual organisms.
Changing environments cause organisms in populations to have differential survival.*
Reproduction will cause variances over time in populations.*
Limiting factors can reduce the number of organisms in certain populations.*
Mutations will occur in populations over time in changing environments.*
Populations over generations will adapt to changing environments.*
Carrying capacity could be reached in some populations in changing environments.*

Total Propositions=20; ScientificPropositions=13; 10/13= Evolutionary (77%)

Note: Evolutionary Propositions are noted with *
Appendix C1: Paige

Paige (ECO+E) Explanations for Tasks-Ontological and Epistemological Beliefs

Task 1
Since the brown foxes are more easily noticed, they weren’t able to catch as much food as the white foxes could. This meaning many brown foxes died off because of starvation from not being able to hunt as well in the winter because of their fur color. The white foxes blend more easily into their surroundings therefore their prey couldn’t spot them and couldn’t escape quick enough which, is why there are more white foxes than there are brown foxes.

Presuppositions: Terminal-sequential, direct-process ontology
Suppositions: Proximate conception; causation in present; enrichment/revision-ecological conceptions

Task 2
They developed these features of thousands of generations due to having to adapt to their surroundings in order to survive. The need to survive caused them to gain mutations in their genetics making them harder to spot like Carolina mantids in alfalfa fields, or look like different species, like a species of butterflies that look like monarchs because monarchs are poisonous to the predators in the same habitat of the butterflies.

Presuppositions: Intentional, terminal-event direct-process ontology
Suppositions: Teleological conception; causation in present; drew from class examples; indicates change over time without cause.

Task 3
Since the green beetles cannot camouflage themselves on the ground or tree trunks they are easily seen by predators, causing their species’ number to drop. Since the brown beetles have more places to roam without being detected by predators their numbers are more plentiful. This creates an imbalance between the green and the brown beetles. The brown beetles don’t have much competition for food since the green beetles are not as abundant.

Presuppositions: Terminal-intentional, direct-process ontology
Suppositions: Proximate conception; causation in present; enrichment-ecological conceptions.

Task 4
These characteristics have become natural over thousands and thousands of generations. Starting when a species that needs to adapt to a new environment. Minor mutations in genetic coding begin, becoming more noticeable over thousands of years. Camouflage is necessary for survival. Not just for species who need to hide from there predators but species like the arctic foxes who must camouflage themselves so they are not seen by their prey. If a species doesn’t have a good camouflage they will either, be eaten quickly or not be able to catch food since their prey can see them coming. These small details grow more noticeable over thousands of generations.

Presupposition: Goal-terminal, intentional, direct-process ontology
Suppositions: Teleological conception with evolutionary character-population change over time; natural selection concepts-adaptations, differential survival, inheritance.

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.

Paige (ECO+E) Reflections-Ontological Epistemological and Motivational Status

Pre-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Q-How did some finches survive the catastrophe, while most finches did not? (Intervention)
Some finches adapted to the lack of rain and their beaks grew to a longer length to be able to eat a different food supply. Since the main food source was hard tribulus seeds, the parents
Ontological/Epistemological Status:
Goal-intentional-direct-process ontology; enrichment/revision-ecological conceptions.

Post-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Q- How did some finches survive the catastrophe, while most finches did not? (Intervention)
As the amount of rainfall lessened, their researched showed the finches beaks grew longer during that period. The graphs on the rainfall, seeds, and beak sizes shows a decrease in rain and seeds, and the beaks grew longer. The tribulus seeds were the only seeds that were still plentiful during that period. The seeds rigidity is hard which means if the finches adapted to eating those seeds their beaks would strengthen and become larger. The survivors had longer and stronger beaks able to eat hard seeds. It gave them an advantage because they could eat a more plentiful food supply while the others couldn’t
Q- Why did some finches survive? (Intervention)
Some birds adapted to eating hard seeds instead of soft seeds while others did not, causing them to starve.

Ontological/Epistemological Suppositions:
Terminal-intentional, direct-process ontology; enrichment/revision-ecological conceptions;
on-tology seems coherent, plausible explanation, committed.

Pre-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
The environment effected how well and how fast a bug can blend in and camouflage into the background, therefore affecting the bugs’ ability to hide from predators and the size of the population. For instance the bugs blended into the poppy field faster than that of the glacier, making the poppy field more an opportunity to expand the population than the glacier. [same as partner]
Q- Why do some bugs develop camouflage? (Intervention)
The easier the bugs were able to blend into the environment, the bigger the population numbers. The poppy field had a lot of bright, distracting colors, making it easier for the bugs to survive and expand in number.

Ontological/Epistemological Suppositions:
Goal- intentional, direct-process ontology-presupposition; no attempt to give proximate causation. ontology seems coherent, plausible explanation, committed.

Post-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time? Q- Why do some bugs develop camouflage? (Intervention)
If the environment suddenly changes, bugs won’t be able to adapt immediately to the new changes. If more species of predators arrive then the species could die off because of predation, if a predator species dies off there will be more of the species of bugs.

Ontological/Epistemological Suppositions:
Enrichment-ecological conceptions; this may indicate student understands that individuals do not adapt. Calls into question previous teleological responses.

Post Argument
Q- Is your claim scientific? Explain.
GF- Yes, the claim that we made was scientific because, it involved reading and understanding the data that the Grant’s collected. [Low-no justification/reasoning]

BH- Yes, our claim is scientific because we researched and studied data, and came to a conclusion based on our findings. [High]
Suppositions: Mixed source/justification; Tasks plausible, comprehensible, coherent

Q- What evidence did you use to support your claim?
GF- As the amount of rainfall lessened, their research showed the finches beaks grew longer during that period. [High]
BH- We used the evidence of the bugs beginning to disappear the longer we would hunt them. [High]
Suppositions: High-source/justification, though not specific; Tasks-plausible, coherent, comprehensible

Q-Did your claim change when you saw conflicts in data during your argument? Explain.
GF- No, our claim didn’t change due to the fact the Grant's data supported the claim. [High]
BH- Our claim did not change during the activity. [Low]
Suppositions: Mixed-certainty/development: BH-did not support reasoning

Q- Where there any patterns in the evidence? Give specific examples if necessary.
GF- When the rainfall lessened the food for the finches lessened as well, causing them to fight over food and find a new food supply, such as the tribulus seeds. [High]
BH- One pattern was we would catch more when we hunted for longer periods of time than when we hunted in a short amount of time. [High]
Suppositions: High-source/justification, though very simple example; BH task- high social context

Q- How is your argument similar to an argument a professional scientist would make?
GF- Our argument is similar to what a professional scientist would say because both of our arguments involve understanding and reading data. [Low]
BH- Our argument is similar due to the fact we did what professional scientists do to create an argument, we researched and came to logical conclusions based on the data we acquired. [High]
Suppositions: Mixed certainty/development dimension; Tasks- high social context

Q- Where do you find scientific knowledge?
BH- Anywhere in a field of science. Scientific knowledge is knowledge gathered from things you already know and newly gained information and data. [High]
Suppositions: High source- individual knowledge; Certainty implied

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
BH- When I randomly see butterflies or bugs I will think of ways they adapted to predation and their environments. It is very important knowledge that everyone should have. [Low]
Suppositions: Low personal relevance; reasoning not rhetorically compelling

Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
GF- Yes, we spent a lot of time reading and looking at the graphs to learn about what the finches did over the time period. We answered the investigative question completely by understanding the research. [High]
BH- Yes, I followed all guidelines and answered every question to the best of my ability. We both came up with equally logical claims and combined them. [High]
Suppositions: High- self-efficacy; high certainty/development

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?
GF- Learning about the finches and their environment was very interesting and enjoyable. [Low]

BH- It was very enjoyable. I had fun messing around with different variables that base a species survival. I had lots of fun and didn’t get frustrated often. [High]
Suppositions: Mixed motivations; GF task- very general answer; low personal relevance

Q- What grade would you give yourself on this activity? Explain.
GF- I would give myself a B on this activity. Some of our explanations weren’t as good as they should have been but I participated well and did a good job. [High-reason]
BH- ‘B’, our justification and evidence could have been more detailed. [High-reason]
Suppositions: High-grade motivation, gave reasoning; High self-efficacy- can be critical of work

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:

Ontology/Epistemology

Student's ontological and epistemological presuppositions seem to be coherent, edirect processes with varying features, primarily terminal and goal.

Student's written explanations all reflect this ontology and are reflected in her consistent proximate causation reasoning in two narratives (Tasks 1 and 3). Student shows basic understanding of mechanism for variations and differential survival of individuals and enrichment/revision-ecological conceptions.

Student showed teleological conceptions in her declarative responses to Tasks 2 and 4, but had evolutionary conceptions with proximate causation.

Student response to post-argument after bug modeling may indicate student understands that individuals do not adapt. Calls into question previous teleological responses.

Epistemic beliefs are rated overall high (8/11=73%), shows minimal to satisfactory understanding of nature of scientific knowledge. These scores are close to the average pre and posttests scores on SEB instrument (4.0/5=80%).

Motivations

She scored relatively high (e/4) on self-motivations in her reflective questions. Student's written reasoning suggests that she has high self-efficacy and can defend her claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about her work within the group. She displayed persistence when given more autonomy in inquiries and expressed that she liked the inquiries. This student struggles academically in school, but her reasoning for her grades gave her a grade/career motivations of 67% (2/3). The average for her pre and posttest scores on the SMQII are 3.11 (62%) This score is lower than the reflection scores of 71% (3/4+2/3=5/7).

Mental Model- The student's ontological and epistemological framework structure indicates to she is forming new connections between concepts. Both her pretest and final tests have network structures with more connections on her final test. She shows improvement in declarative, evolutionary conceptions throughout intervention (60%–888%). She had 5 scientific propositions of 15 (33%) total on her pretest with 3/5 evolutionary conceptions. When forced to create connections from her cognitive map structure for her posttest, she produced only 3 scientific propositions from 14 propositions (3/14=21%). She shows enrichment and revision of conceptions through Final Test producing 8/17 (47%) scientific conceptions and 7/8 evolutionary conceptions. Her proposition complexity also increased during this study. Her CINS score improved from a score 5 to 10 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development.
Paige (Eco+E) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Changing environments affects an ecosystem.
Genes affect individual organisms.*
Reproduction leads to individual organisms.*
Individual organisms make up populations.
Populations are due to the success of reproduction.*

Total Propositions =15; Total Scientific Propositions =5; 3/5=Evolutionary (60%)

Scientific Propositions (Posttest)
Changes in an ecosystem may create new limiting factors.*
Limiting factors effect a species survival causing differential survival between organisms of the same species.*
Individual organisms have different survival rates or differential survival.*

Total Propositions= 14; Scientific Propositions=3; 3/3=Evolutionary (100%)

Scientific Propositions (Final Test)
Genetic variations are mutations that allow species to develop new features (over thousands of years) in order to survive.*
Genetic variations affect a species differential survival by adapting tools for them to survive better over thousands of years.*
Mutations in the genes may allow a species to adapt and survive over many generations.*
Changing environments changes a species differential survival by setting new standards for the species to live in.*
Limiting factors are things that interfere with a organism's life (like predators, food supply, and shelter) which set standards for carrying capacities.*
Populations can be changed when a new standard of limiting factors is established.
Populations survival can be changed dramatically by a change in the environments carrying capacities.*
Populations must adapt (over thousands of generations) to survive in changing environments.*

Total Propositions=17; Scientific Propositions=8; 7/8= Evolutionary (88%)

Note: Evolutionary Propositions are noted with *
Paige (ECO+E)  Concept Map Structures with Cognitive Map

Pretest-Network Structure

Cognitive Map

Posttest- Tree Structure

Final Test-Network Structure
Appendix C1: Stuart

**Stuart (ECO) Explanations for Tasks-Ontological and Epistemological Beliefs**

**Task 1**

With the white foxes, the winter snow makes them be able hide themselves from predators. The white fur on foxes matching the white in the snow, which makes them be able to camouflage themselves from predators. The brown foxes stand out more in the white snow, which makes them an easier target for predators to be able to spot. When the winter was no in effect yet, the two kinds of foxes were on equal territory for predators because neither one of them were able to camouflage themselves a great deal from predators. Since they are both equal easy to spot, they are both targets for predators which make their proportions the same. When winter came, the white foxes were at an advantage and were able to hide themselves from predators much easier, which makes the survival rate for the white foxes much higher than the brown foxes, which makes the proportion for the foxes change.

*Presupposition:* Goal, intentional-direct-process ontology  
*Suppositions:* Teleological conception with proximate causation.

**Task 2**

Over time these animals will develop these particular features so that they can survive much easier. Over time, the animals will pass down new traits and genes to their offspring that allows for them to be able to have these features. Over time, the animals will adapt to their environment and there surrounds, like there predators, and be able to find ways to adapt to the environment and use it to their advantage to survive. Animals that live in a certain community for long periods of time will take in their surrounds in their environment and find ways to use it to their advantage in order to survive. Animals know that they must adapt to their environment because of past experiences, just as us humans do. These past experiences drive animals into evolving and become able to create feature that helps them survive.

*Presupposition:* Intentional-direct-process ontology  
*Suppositions:* Teleological conceptions- learn from past experiences.

**Task 3**

Since the brown beetles were able to hide themselves from predators, they survived more than the green beetles. The green beetles were a brighter, more noticeable color than the brown beetles when compared to the leaves, since they were not camouflaged with the leaves that left them more of a target for predators. The brown beetles were able to blend in with the leaves much better than the green ones since they were able to use their color to their advantage. There is evidence it that the brown beetles were able to hide themselves from predators because now we cannot find as many green beetles. Predators must have moved to the area and they were able to spot the green beetles as their food source. Brown beetles were able to survive more because they were able to camouflage themselves in the environment.

*Presupposition:* Goal, intentional-direct-process ontology  
*Suppositions:* Teleological conceptions- learn from past experiences.

**Task 4**

Over time the animals develop to be able to adapt to their environment. Genes get passed on that help animals within their environment, which over time, allows for animals to adapt to a color that helps them survive. Over time animals learn to help themselves survive within their environment, and they make certain changes that allow them to do so. Most changes are necessary for their survival. If needed, animals could move to another area in order to survive, they could go to an environment that had the resources they need. Animals learn to adapt to their environment and pass their genes to newer generations.

*Presupposition:* Goal, intentional-direct-process ontology  
*Suppositions:* Teleological conception-learn from past experiences.

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.
Stuart (ECO) Reflections-Ontological Epistemological and Motivational Status

Pre-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
In this case more finches survived the wet season than the dry season. Once carrying capacity was reached, the population decreased with time. More finches survived in the wet seasons then the dry seasons because there was more resources in the wet for the finches.
Ontological/Epistemological Status:
Enrichment/revision-ecological conceptions

Post-Argument Reflection- Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Once carrying capacity was reached, the population decreased with time. More finches survived in the wet seasons then the dry seasons because there was more resources in the wet for the finches.
Ontological/Epistemological Status:
Enrichment/revision-ecological conceptions

Pre-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
It can increase or decrease depending on the conditions of the environment, the color of the bug, and how well that bug can camouflage itself in the environment. The environment can increase of the bug population if there are similarities in the colors of the bugs and in the environment. A bug will have a better chance of living if they can find similar colors in the environment because predators will have a harder chance of finding them. A bug has a large chance of dying if they cannot camouflage themselves in the environment because they make easy targets for predators since they are easy to see.
Ontological/Epistemological Status:
Goal-direct-process ontology; purposeful directed intentions; natural selection concepts-variation, differential survival

Post-Argument Reflection- Bug Hunt
Q- How do environmental factors influence a bug population over time?
The environment would influence the bugs to become more like the environment. The current bugs would pass down genes to the new bugs over time so that they adapt to the environment and look like it in order to camouflage themselves. Over time the bugs would become similar to the colors in the environment in order to camouflage themselves from predators.
Ontological/Epistemological Status:
Goal-direct-process ontology; intentionality given for camouflage; natural selection concepts-inherited variations; ontology seems coherent, plausible explanation, committed.

Post Argument
Q- Is your claim scientific? Explain.
GF- Yes are claim was scientific. We used collected data from studies to support, and make up our claim. Are claim was based on the data that scientists had collected from their studies on the finches. [High]
BH- Yes our claim is scientific because we observed data, made a claim, and provided evidence to support our claim. We used facts that we found while doing the bug hunt and used those facts to come up with an ideal claim that we felt was good and that we could back up with evidence. We did not state anything that we could not back up with evidence. [High]

Suppositions:
High source/justification dimension, individual generation of knowledge-high certainty; Tasks-comprehensible, plausible, coherent; high social context

Q- What evidence did you use to support your claim?
GF- We mostly used evidence from graphs, such as the amount of rainfall, and finch population graph. We used the rainfall graph to determine how the amount of food changes in the wet and dry seasons, and we used the finch population graph to see how the pattern of the finches was affected by limiting factors was over time. [High]
BH- We used evidence from what we observed in a series of trials to support our claim. We only used evidence from what we saw; we did not make anything up from our claim. We used evidence that showed how much an environment effects a bug population. We used evidence that showed how bugs have to adapt to an environment in order to survive. [High]

Suppositions: High source/justification dimension; tasks-plausible, comprehensible, coherent; high social context; teleological explanation

Q-Did your claim change when you saw conflicts in data during your argument? Explain.
GF- No our claim did not change when we saw conflicts in data because no matter how big the problems were, our claim could not have changed because it was still supported. [High]
BH- No our claim did not change during our experiment. We experienced the same results that we stated in our claim in each trial that we conducted. In each trial we experienced that same kind of habits by bugs in order to protect themselves from predators, so our claim stayed the same throughout the entire activity. [High]

Suppositions: High-certainty/development dimension; high social context; tasks-comprehensible, plausible, coherent/persistent need-based/teleological explanation

Q- Where there any patterns in the evidence? Give specific examples if necessary.
GF- Yes there were patterns in the evidence. We saw that as the amount of rainfall dropped over time, so did the finch population. [High]
BH- Yes there were patterns in our evidence. We often repeated that in each environment, the bugs had to eventually adapt to the environment in order to survive from predators. With time in each environment, the bugs would learn to camouflage themselves to hide from survivors. [Low-no cited evidence]

Suppositions: Mixed source/justification dimension; coherent/persistent need-based/teleological explanation

Q- How is your argument similar to an argument a professional scientist would make?
GF- We used data from graphs to support our claim, just as a scientist would. Scientists would use the data they collected 'to form a conclusion, just as we did. Scientists do not pull a claim out of thin air with any data supporting it; they would have evidence to back their claim up, just as we did. Since they used the same data as we did, we would be using the same facts to make a claim, so there could be a similarity in our arguments. [High]
BH- Our argument is similar because we answered our focus question, made a statement, and used evidence to support our claim. We did not ‘un-support’ anything that we stated in our claim, just as a professional scientist would do. [High]

Suppositions: High source/justification dimension; high social context; high certainty; high self-motivations, self-efficacy, need for cognition/intrinsic motivation

Q- Where do you find scientific knowledge?
BH- We find scientific knowledge from experiences in life and by doing experiment and trials to answer our questions we have about the world. [High]

Suppositions: High source and certainty dimensions;

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
BH- We will use this knowledge all throughout our life. Not necessary the things we study, but he habits we learn in the process. We will use this information to make statements in life, and to help us get a better understanding of how our world works around use. The things we learn will help us be better prepared for our future experience in life.
I think that it import knowledge because it is good to know how the world around us works and operates. I think that learning means that we get a good general idea of things that we study and that while we study; we develop habits that help us beyond high school and in our life. [High]

Suppositions: High self-determination/autonomy, self-efficacy, personal relevance; rhetorically compelling

Q-Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
GF- Yes I feel that we met all goals in our argument. I think that we covered all parts to the argument in our claim and evidence. We answered all the questions, came up with a valid claim,
and used evidence to support our claim. I think that we answered the question fully, and in detail. [High]
BH- Yes I feel as though we fully answered the argument a met our requirements. We tried hard to form a claim, had good evidence, and connected our thoughts from our claim and evidence very well. *We used the data* to support everything we stated, and tried hard to meet all requirements. We explained our focus question, and discussed how the environment effects a population. [High]

**Suppositions:** High self-efficacy, need for cognition/intrinsic motivation; high social context

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?

GF- I liked using data. The data made making a claim much easier, and it made using evidence much easier. Data helped explain what was going on in the website, and it contributed to our research and claim.
I felt like I learned a lot from this activity. Doing this project *on our own helped us* learn how to hunt for our answers, rather than our answer being very easy to find. This is important to know *how to do because later in our life, we will have to find our answers, they will not be as easy to come across.* Learning about the finches was also interesting. I got frustrated a few times when finding an answer was a bit more difficult, but I always took my time and found it. This activity was much more fun they doing a project while just using our text book. [High]

BH- I liked the computer modeling part of the activity because it was an easier way of seeing how our focus question works. It was easier than going outside, finding a bug population, and watching it I order to answer our question. I liked to see how the different variable effects the environments, I liked change the bug size the best. I liked to be the predator and catch the bugs, because it was sometimes a challenge to see and find the bugs. The graphs were helpful because we were able to see how each variable affected the environment over time.
I feel like I learned from this activity. I think that this added to my knowledge because I was able to see how variables and other things effect an environment, and I had to observe and watch in order to find this. I did not get frustrated in this activity much, except when the time did not work on our trials. This activity was fun with each trial. [High]

**Suppositions:** High autonomy/self-determination; high social interest; tasks-plausible, comprehensible, coherent

Q- What grade would you give yourself on this activity? Explain. (grade motivation, self-efficacy, need for cognition/intrinsic motivation)

GF- I would give myself an A-. I feel like our answers were accurate and well written with evidence. I think that we could have may included a bit more detail within the questions, therefore an A-. but overall, I think that our project was well organized, accurate, and correct. [High]

BH- I would give myself an A on our project because *we took our time*, tried hard, and *came up with a good claim that answered our focus question with much evidence and justification*. We did not leave any statement we made without any evidence to support it. [High]

**Suppositions:** High-self-motivations, self-efficacy, self-determination/autonomy; grade motivations

**Notes:** Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= *Galápagos Finches* (bguile.northwestern.edu) activity; BH= *Bug Hunt Camouflage* (Novak & Wilensky, 2006).
Researcher Interpretations:
ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS

Ontology/Epistemology
Student's ontological and epistemological beliefs seem coherent, direct process with varying features, primarily goal or intentional. Reflections reveal alternate conceptions about animals learning to adapt to environment. He assigns intentionality as mechanism and use environment for individual survival. Stuart's teleological conceptions are consistent and coherent in all task explanations and in reflection responses. Student's written explanations all reflect this ontology and are reflected in his coherent teleological conceptions in narratives.

Interestingly, the focus question for the bug hunt was similar to the finch question, with the added condition of time. Stuart made no attempts to explain phenomena using teleological conceptions in his explanations about the finches. However, with the time constraint, his explanations became overtly teleological.

Epistemic beliefs are rated overall high (10/11=91%) on his reflection responses, and shows basic understanding of nature of scientific knowledge. This is a higher rating than student's average pre-, post-survey scores on SEB instrument (3.75=75%).

Motivations
Results (4/4) on self-motivations indicate; student's written reasoning suggests that he has high self-efficacy and can defend his claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about his work. Response to personal relevancy score was high on career and grade motivations (3/3). He reported that he liked both inquiries and enjoyed autonomy, but felt he had rushed on the bug modeling inquiry. Overall his motivational score on the post survey was lower mean gain (0.44) with an average score of 3.74 (75%). His reflection scores were higher than the SMQII survey to the reflection scores of 100% (4/4+3/3=7/7).

Mental Model- Student's ontological and epistemological final framework structure was network like with more connections between concepts, when compared to his pretest, tree/spokes structure. There was improvement in the number (3) declarative, evolutionary conceptions from the pretest to final test. He shows enrichment and revision of conceptions through final test. Four of 7 scientific propositions were evolutionary on the pretest, 6/10(60%) evolutionary conceptions on the posttest, and 7/13 (54%). His CINS score improved from pretest to posttest with a score 6 to 9 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development. This final score was the lowest in the ECO class.
Stuart (ECO) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Genes are what makes individual organisms.
Populations cannot expand larger than carrying capacity.*
Populations are made up of individual organisms.
Limiting factors decreases growth of populations.*
Ecosystems contain different populations.
In ecosystems some organisms have differential survival.*
Reproduction increases populations in ecosystems.*

Total Propositions=12; Scientific Propositions =7; 4/7=Evolutionary (57%)
Stuart (ECO) Concept Map Structures with Cognitive Map

Pretest-Tree Structure

Cognitive Map

Posttest-Network Structure

Final Test-Network Structure
Task 1
Since prey could much more easily escape the brown foxes, while the white colored foxes moreover easily captured food, the brown colored foxes struggled to survive to reproduce and pass on the brown colored gene compared to the white foxes. Because of this, as generations of foxes went on, and brown colored foxes slowly decreased in number compared to the white foxes due to the disability to capture food, the brown gene slowly decreased in number being passed on in offspring, slowly increasing the numbers of white foxes and decreasing the brown ones.

Presupposition: Terminal-direct-process ontology/ genes as matter
Suppositions: Evolutionary conception- population change through time; proximate causation; natural selection concepts-variation, differential survival, inheritance

Task 2
Camouflage is developed through variations in genes slowly being more and more mutated through each generation to better enhance the species chances of survival. An organism has much more of a chance hiding from predators and prey alike if it blends into its environment rather than stand out. Another prime point is the concept of ‘survival of the fittest’, meaning the individual that best has features and advantages for the environment they live in will survive before an individual that does not. For example, an individual who has a mutation of green colored skin in a green rainforest will survive rather than one who has bright orange skin. Thus, the green skin will more likely be passed down generations and perhaps mutated more to blend into the environment.

Presupposition: Intentional-direct-process ontology
Suppositions: Teleological conception with evolutionary character- population change through time, inherited variation, differential survival; possible faulty causation-‘mutated more to blend'

Task 3
Since the brown beetles had a better survival advantage in their color variation from that of the green beetles, these were the beetles who mostly survived and passed down the brown colored variation to the next generation and through many more until brown was the common color of beetles in this environment.

Presupposition: Terminal-direct-process ontology
Suppositions: Evolutionary conception- population change through time; proximate causation; natural selection concepts-variation, differential survival, inheritance

Task 4
These animals develop these camouflaged disguises through mutations and variation in the DNA that slowly develops through many generations. This variation may help the species survival rate. Such as, if the variation doesn’t help the survival rate, that individual has less of a chance of surviving and passing on said variation. Eventually the mutation becomes an actual part of the DNA setting through evolution.

Presupposition: Terminal-sequential, direct-process ontology
Suppositions: Evolutionary conception- population change through time; proximate causation; natural selection concepts-variation, differential survival, inheritance; potential teleological conceptions ‘if the variation helps’, but clarified. 'DNA setting’=gene pool.

Note: Italicized phrases and words are coding; Punctuation and spelling corrected.
Appendix C1: Zena

Zena (ECO+E) Reflections - Ontological Epistemological and Motivational Status

Pre-Argument Reflection - Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Q-How did some finches survive the catastrophe, while most finches did not? (Intervention)
Some finches adapted to the lack of rain and their beaks grew to a longer length to be able to eat a different food supply. Since the main food source was hard tribulus seeds, the parents needed to adapt to eating hard seeds. Those made their beaks become stronger and larger. This was passed from parent to offspring through evolution.
Ontological/Epistemological Status:
Goal, terminal, direct-process ontology-individual adaptation; No response to first question-enrichment/revision-ecological conceptions

Post-Argument Reflection - Finches
Q-How did limiting factors influence the finch population on Daphne Major?
Q- How did some finches survive the catastrophe, while most finches did not? (Intervention)
Some finches had the adaption to the low rain rate with the genetic growth of their beaks to help crack and eat the harder shells left only after the catastrophe. Survivors seemed to carry a trait of bigger beaks, which helped them in the competition for the resources left from the lack of rain [the hard seeds]. Being able to crack and eat these seeds easier and faster with larger beaks rather than those with smaller beaks helped the survivors eliminate those who died off.
Q- Why did some finches survive? (Intervention)
They had inherited traits that would help them survive in certain situations, in this case larger beaks for food leftover from a catastrophe of not enough rainfall.
Ontological/Epistemological Status:
Goal, intentional, direct-process ontology; proximate causation; natural selection concepts-variation, differential survival; ontology seems coherent, plausible explanation, committed.

Pre-Argument Reflection - Bug Hunt
Q- How do environmental factors influence a bug population over time?
The environment effected how well and how fast a bug can blend in and camouflage into the background, therefore affecting the bugs’ ability to hide from predators and the size of the population. For instance the bugs blended into the poppy field faster than that of the glacier, making the poppy field more an opportunity to expand the population than the glacier. [same as partner]
Q- Why do some bugs develop camouflage? (Intervention)
Bugs develop camouflage by blending into their environment to better protect themselves from predators and have their species survive over thousands of years, which is how the camouflage developed. The environment in which the species lives in influences the bugs’ body colors and patterns as camouflage over this time.
Ontological/Epistemological Status:
Goal-event, direct-process ontology; enrichment-ecological conceptions

Post-Argument Reflection - Bug Hunt
Q- How do environmental factors influence a bug population over time? Why do some bugs develop camouflage? (Intervention)
The environment and how well the bug thrives and can hide in it determines whether it can live and if a predator can easily find and capture the bugs. The predator itself determines an individual bugs life. The gene for color eventually changes in the population as a whole through evolution and adaption for survival. If a bug with a slight variation survives and reproduces in an environment where color change is needed for species survival, the offspring will change more in color slightly, and pass that onto its offspring if survival is granted.
Ontological/Epistemological Status:
Event/need-based, direct-process ontology; proximate causation; natural selection concepts-variation, differential survival, inheritance; ontology seems coherent, plausible explanation, committed.
Q- Is your claim scientific? Explain.
   GF- Yes, our claim was scientific because it has the main topic of our scientific argument and details to support it. [Low-evidence not specific]
   BH- Yes, our claim listed exactly what our argument consisted of and what our answers to the investigation questions were. [Low]
   **Suppositions:** Low-source/justification dimension; high social context

Q- What evidence did you use to support your claim?
   GF- As the amount of rainfall decreased, research in charts showed the finches beaks growing longer during this period of dryness. [High]
   BH- We used evidence we drew from the activity we did as predators hunting bugs as they slowly varied in color. [Low]
   **Suppositions:** Mixed source/justification dimension; Tasks-comprehensible, plausible, coherent

Q- Did your claim change when you saw conflicts in data during your argument? Explain.
   GF- No, because data and evidence in the charts and investigation supported our claim. [High]
   BH- No, the activity fully supported our claim that a species evolves and goes through variations and mutations over generations to survive in an environment. [Low]
   **Suppositions:** Mixed certainty/development dimension;

Q- Where there any patterns in the evidence? Give specific examples if necessary.
   GF- In the charts, rainfall and most seeds on the floor matched up, showing a pattern. Such is that when rain lessened in 1977, most seeds on the floor also lessened a great deal. The only exception would be the plentiful number of harder Tribulus seeds found scattered on the ground throughout the island even after the rain decreased starting in 1977, thus being the evidence matching up to the reason that as the amount of rain decreased, finches evolved to having bigger beaks. [High]
   BH- Yes, if we changed the bug size, we noticed that in every background that the bigger the bugs, the less they blended in, and therefore the more were caught. With the mutation level as well, the faster the mutation and color changing set in, the less bugs were caught. [High]
   **Suppositions:** High source/justification; social context-BH

Q- How is your argument similar to an argument a professional scientist would make?
   GF- A professional argument contains a claim, plenty of evidence, and justification and reasoning to go along with it. My scientific argument contains these elements as well.[High]
   BH- In a professional argument, a claim is made, evidence is shown from an activity or experiment of research and proof, and a justification relating evidence to claim is provided. In our argument, we have all these factors. [High]
   **Suppositions:** High-certainty/development dimension; high self-efficacy, social context

Q- Where do you find scientific knowledge?
   BH- In our evidence from the activity we did on bug camouflage and predator relations. By conducting experiments and through research. [High]
   **Suppositions:** High-source- individual generation of knowledge

Q- How do you use scientific knowledge? What does learning science or studying science mean to you?
   BH- Well personally, I want a career in the scientific field. But I think that anyone would benefit from knowing more about the world they live in and how things around them work, how their body works, anything about the natural world and laws we all depend and thrive on. I think that scientific knowledge is a very important thing. Science explains some of the most important things in our lives. How we live. How we breathe. How we keep our population going. How the earth works as a rare planet that can support life. Scientific knowledge explains so much, and still is developing. Everything about the universe, everything around us can turn into a scientific question. Finding the answers, or trying to, and then coming closer to a solution, is learning. [High]
   **Suppositions:** High-development dimension, personal relevance; rhetorically compelling

Q- Do you feel you answered the investigative question fully in your argument and met the goals of this investigation?
GF- Yes, I don’t see any other points to be made in this argument or any other evidence to list. With the evidence and reasoning listed in our scientific argument it’s enough to make a valid point. [High]
BH- Yes, we answered both focus questions fully between our claim and justification, plus the evidence to prove the claim. We made a point to make sure to fully explain and use our evidence as well as explain it through our justification. [High]

Suppositions: High self-efficacy; high social context

Q- How do you like this type of activity? Explain. How do you feel about your learning during this activity?
GF- I liked it because it was interesting to look for answers and to figure out how our argument based on our answers would turn out. Make justifications to prove my argument. The only times I got frustrated was when I couldn’t find certain information or I actually enjoyed searching data to make a claim on my own and then find evidence to answers to some questions. [High]
BH- Overall I enjoyed this hands-on activity. It was fun to see the results differ with just a slight single change of environment, bug size, or mutation, etc. Personally the only problem I had was that the time on the activity on my computer gave me a lot of trouble, because it wasn’t working correctly, but otherwise it was fine. [High]

Suppositions: High autonomy/self-determination; intrinsic motivation

Q- What grade would you give yourself on this activity? Explain.
GF- I would give the two of us fair grades on effort and on how the argument is set up. Personally I know we tried and I think that our argument was setup correctly with enough evidence and justification to support our claim. [High]
BH- I would give our effort a decent percentage. As far as I feel, I think we understood the activity’s concepts and the lesson behind it. I also think that our argument structure improved from our last argument because we spent specific time trying to expose and explain our evidence correctly, and then made sure to justify it afterwards. [High]

Suppositions: High self-efficacy; grades not specified/high intrinsic motivation/need for cognition

Notes: Italicized phrases and words are coding; Epistemological and motivational ratings in brackets; GF= Galápagos Finches (bguile.northwestern.edu) activity; BH= Bug Hunt Camouflage (Novak & Wilensky, 2006).

Researcher Interpretations:
ONTOLOGY/EPISTEMOLOGY/MOTIVATIONS
Ontology/Epistemology
Student's ontological and epistemological beliefs seem to be coherent, even, direct-process ontology with varying features, primarily goal and terminal. Reflections revealed goal-event teleological conceptions—implies individual adaptation. Constructed only one teleological narratives on tasks. Supports Chi’s assertion on event processes (not p-prims!)?
Student's written explanations all reflect this event ontology and occur consistently in her reflection responses. She gives proximate causation reasoning in narratives. Student explanations for tasks show basic understanding of mechanism for variations and differential survival, and population change with time. uses concepts like 'evolution', 'survival of the fittest'- not mentioned in class. (Student reading on own?)
Fourth task response hints of goal-event mutation.

Epistemic beliefs are rated overall high (7/11=64%), shows satisfactory understanding of nature of scientific knowledge. These scores are lower than the self-reported final score on SEB (4.21/5=84%).

Motivations
Results (4/4) on self-motivations indicate; student's written reasoning suggests that he has high self-efficacy and can defend her claims through argumentation. Student displayed higher characteristics of autonomy and self-determination, and expressed that about his work. High rating on response to personal
relevance and career motivation (3/3) with two high scores in grade motivations. She reported that she liked both inquiries and enjoyed autonomy. Displayed persistence when given more autonomy in inquiries. Overall her motivational score on the post survey was lower mean loss (-0.09) with an average score of 4.40 (88%). This score is similar to the reflection score of 100% (4/4+3/3=7/7).

Mental Model- Student's ontological and epistemological framework structure (pretest and final test) is more circular like with connections between concepts. There was improvement in declarative, evolutionary conceptions throughout tested period (0%-78%). She shows enrichment and revision of conceptions through final test. Two propositions of 11 total propositions were scientific on the pretest, 10/23 on the posttest, and 7/9 on the final were scientific propositions. She did not construct any evolutionary propositions on the pretest, 7 of 10 (70%) evolutionary conceptions on the posttest, and 7/9 (78%) evolutionary conceptions on the final test. Her CINS score improved from a score 7 to 10 out of a possible 20. This shows enrichment and revision of conceptions and improved conceptual development.

Zena (Eco+E) Declarative Knowledge from Concept Mapping Propositions

Scientific Propositions (Pretest)
Genetic variations occur on certain genes.
Mutations are a type of genetic variation.

Total Propositions=11; Scientific Propositions =2; 0=Evolutionary (0%)

Scientific Propositions (Posttest)
Reproduction increases or maintains the population size.
Reproduction creates an offspring, to which genes are passed down from parents.*
Changing Environments affect the population’s size.
Changing environments affect the individual organism's survival chance and living style.*
Limiting factors influence the population numbers.
Limiting factors affect the individual organism's chance of survival, differential survival.*
Changing environments influence differential survival.*
Mutations in an individual can cause variation, leading to differential survival.*
Genetic variations may take place in certain genes.*
Reproduction can pass on mutations in the DNA to offspring.*

Total Propositions=23; Scientific Propositions=10; 7/10=Evolutionary (70%)

Scientific Propositions (Final Test)
Individual organisms live in populations.
Populations live and strive in ecosystems.
Genes get passed onto offspring through heredity.*
Reproduction rates contribute to population size.*
Populations cannot survive in exceeding in number above the carrying capacity.*
Limiting factors may change during changing environments.*
Changing environments can influence differential survival.*
Differential survival can result from genetic variations.*
Genetic variations occur in individual organisms.*

Total Propositions=12; Scientific Propositions=9; 7/9= Evolutionary (78%)

Note: Evolutionary Propositions are noted with *
Zena (ECO+E) Concept Map Structures with Cognitive Map

**Pretest-Circular Structure**

**Cognitive Map**

**Posttest-Network Structure**

**Final Test-Circular Structure**
### Appendix C2: CINS Main Items

#### Table C2
*CINS Item Results by Main Ideas*

<table>
<thead>
<tr>
<th>Main Ideas</th>
<th>Pre-test Mean</th>
<th>Post-test Mean</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biotic Potential</strong></td>
<td>C(n=6) 1.33</td>
<td>E(n=6) 1.00</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Population Stability</strong></td>
<td>C(n=6) 1.00</td>
<td>E(n=6) 1.33</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Resources Limited</strong></td>
<td>C(n=6) 1.33</td>
<td>E(n=6) 1.00</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Limited Survival</strong></td>
<td>C(n=6) 1.00</td>
<td>E(n=6) 1.33</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Variation</strong></td>
<td>C(n=6) 0.83</td>
<td>E(n=6) 0.66</td>
<td>0.83</td>
</tr>
<tr>
<td><strong>Inheritance/Variation</strong></td>
<td>C(n=6) 0.66</td>
<td>E(n=6) 0.66</td>
<td>0.83</td>
</tr>
<tr>
<td><strong>Differential Survival</strong></td>
<td>C(n=6) 0.83</td>
<td>E(n=6) 0.33</td>
<td>-0.33</td>
</tr>
<tr>
<td><strong>Change in Populations</strong></td>
<td>C(n=6) 0.16</td>
<td>E(n=6) 0.16</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Origin of Variations</strong></td>
<td>C(n=6) 0.50</td>
<td>E(n=6) 0.16</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Origin of Species</strong></td>
<td>C(n=6) 0.16</td>
<td>E(n=6) 0.16</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Notes: C= ECO/control group; E= ECO+E/experimental group; *Questions identified by Anderson et al.(2002) as difficult.*
Table C3

*Individual Student Totals for Three Surveys*

<table>
<thead>
<tr>
<th>Student</th>
<th>Total Score</th>
<th>Mean Score</th>
<th>Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CINS</td>
<td>SEB</td>
<td>SMQII</td>
</tr>
<tr>
<td>Andrew (E)</td>
<td>Pretest 9</td>
<td>4.40</td>
<td>4.27</td>
</tr>
<tr>
<td></td>
<td>Posttest 10 (1)</td>
<td>4.33 (-0.07)</td>
<td>4.23 (-0.03)</td>
</tr>
<tr>
<td>Ann (E)</td>
<td>Pretest 5</td>
<td>3.66</td>
<td>3.87</td>
</tr>
<tr>
<td></td>
<td>Posttest 14 (9)</td>
<td>3.57 (-0.09)</td>
<td>4.26 (0.39)</td>
</tr>
<tr>
<td>Bill (E)</td>
<td>Pretest 9</td>
<td>4.44</td>
<td>4.11</td>
</tr>
<tr>
<td></td>
<td>Posttest 11 (2)</td>
<td>4.37 (-0.07)</td>
<td>3.69 (-0.42)</td>
</tr>
<tr>
<td>Brea (E)</td>
<td>Pretest 5</td>
<td>4.40</td>
<td>4.60</td>
</tr>
<tr>
<td></td>
<td>Posttest 13 (8)</td>
<td>4.75 (0.35)</td>
<td>4.55 (-0.05)</td>
</tr>
<tr>
<td>Paige (E)</td>
<td>Pretest 5</td>
<td>4.04</td>
<td>2.80</td>
</tr>
<tr>
<td></td>
<td>Posttest 10 (5)</td>
<td>3.96 (-0.08)</td>
<td>3.42 (0.62)</td>
</tr>
<tr>
<td>Zena (E)</td>
<td>Pretest 7</td>
<td>4.23</td>
<td>4.44</td>
</tr>
<tr>
<td></td>
<td>Posttest 10 (3)</td>
<td>4.19 (-0.04)</td>
<td>4.35 (-0.09)</td>
</tr>
<tr>
<td>Chris (C)</td>
<td>Pretest 6</td>
<td>4.45</td>
<td>3.18</td>
</tr>
<tr>
<td></td>
<td>Posttest 14 (8)</td>
<td>4.27 (-0.18)</td>
<td>3.12 (-0.06)</td>
</tr>
<tr>
<td>Don (C)</td>
<td>Pretest 8</td>
<td>3.84</td>
<td>2.23</td>
</tr>
<tr>
<td></td>
<td>Posttest 12 (4)</td>
<td>4.34 (0.49)</td>
<td>2.41 (0.18)</td>
</tr>
<tr>
<td>Kevin (C)</td>
<td>Pretest 9</td>
<td>4.21</td>
<td>4.21</td>
</tr>
<tr>
<td></td>
<td>Posttest 11 (2)</td>
<td>4.36 (0.15)</td>
<td>3.91 (-0.30)</td>
</tr>
<tr>
<td>Lisa (C)</td>
<td>Pretest 7</td>
<td>4.38</td>
<td>2.99</td>
</tr>
<tr>
<td></td>
<td>Posttest 10 (3)</td>
<td>4.54 (0.15)</td>
<td>2.72 (-0.27)</td>
</tr>
<tr>
<td>Mike (C)</td>
<td>Pretest 10</td>
<td>4.07</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td>Posttest 13 (3)</td>
<td>4.07 (0.00)</td>
<td>3.36 (0.00)</td>
</tr>
<tr>
<td>Stuart (C)</td>
<td>Pretest 6</td>
<td>3.53</td>
<td>3.52</td>
</tr>
<tr>
<td></td>
<td>Posttest 9 (3)</td>
<td>3.97 (0.43)</td>
<td>3.96 (0.44)</td>
</tr>
</tbody>
</table>

Notes: (E)= ECO+E/experimental group; (C)= ECO/control group; Parentheses=(changes in pre and posttest); Student names are pseudo-names.
## Appendix C4: Synthesis of Individual ECO+E Results

### Table C4

**Individual Summary of Student Data from Assessments and Reflections (ECO+E)**

<table>
<thead>
<tr>
<th>Student</th>
<th>Test</th>
<th>Pre-Test Scores</th>
<th>Post-Test Scores</th>
<th>Final Scores</th>
<th>Suppositions</th>
<th>Tasks/Reflections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew (E)</td>
<td>Concept Map</td>
<td>18.0</td>
<td>37.0</td>
<td>43.0</td>
<td>Direct Ontology</td>
<td>1. Teleological</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td>2. Teleological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proposition</td>
<td>1.6 (6)</td>
<td>2.2 (8)</td>
<td>2.3 (12)</td>
<td>3. Teleological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>11.0</td>
<td>17.0</td>
<td>19.0</td>
<td>4. Teleological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolutionary</td>
<td>3.0 (50%)</td>
<td>6.0 (75%)</td>
<td>9.0 (82%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CINS</td>
<td>9</td>
<td>10</td>
<td>-</td>
<td>Reflection Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEB</td>
<td>4.40</td>
<td>4.33</td>
<td>-</td>
<td>High 9/11 (SB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMQII</td>
<td>4.27</td>
<td>4.23</td>
<td>-</td>
<td>High 5/7 (SM)</td>
<td></td>
</tr>
<tr>
<td>Ann (E)</td>
<td>Concept Map</td>
<td>10.0</td>
<td>18.0</td>
<td>16.0</td>
<td>Direct Ontology</td>
<td>1. Description</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td>2. Proximate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proposition</td>
<td>1.1(0)</td>
<td>1.1(2)</td>
<td>1.8 (5)</td>
<td>3. Proximate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>9.0</td>
<td>16.0</td>
<td>10.0</td>
<td>4. Proximate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolutionary</td>
<td>0.0 (0%)</td>
<td>2.0 (100%)</td>
<td>4.0 (80%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CINS</td>
<td>5</td>
<td>14</td>
<td>-</td>
<td>Reflection Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEB</td>
<td>3.66</td>
<td>3.57</td>
<td>-</td>
<td>High 7/11 (SB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMQII</td>
<td>4.27</td>
<td>4.23</td>
<td>-</td>
<td>High 5/7 (SM)</td>
<td></td>
</tr>
<tr>
<td>Bill (E)</td>
<td>Concept Map</td>
<td>32.0</td>
<td>40.0</td>
<td>46.0</td>
<td>Direct Ontology</td>
<td>1. Evolutionary</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td>2. Evolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proposition</td>
<td>2.7 (10)</td>
<td>2.4 (9)</td>
<td>2.6 (13)</td>
<td>3. Evolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>12.0</td>
<td>17.0</td>
<td>18.0</td>
<td>4. Evolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolutionary</td>
<td>7.0 (70%)</td>
<td>7.0 (78%)</td>
<td>11.0 (85%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CINS</td>
<td>9</td>
<td>11</td>
<td>-</td>
<td>Reflection Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEB</td>
<td>4.44</td>
<td>4.37</td>
<td>-</td>
<td>High 8/11 (SB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMQII</td>
<td>4.11</td>
<td>3.69</td>
<td>-</td>
<td>High 6/7 (SM)</td>
<td></td>
</tr>
<tr>
<td>Brea (E)</td>
<td>Concept Map</td>
<td>28.0</td>
<td>39.0</td>
<td>29.0</td>
<td>Direct Ontology</td>
<td>1. Teleological</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td>2. Teleological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proposition</td>
<td>2.0 (5)</td>
<td>1.5 (6)</td>
<td>2.2 (6)</td>
<td>3. Teleological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>14.0</td>
<td>26.0</td>
<td>13.0</td>
<td>4. Teleological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolutionary</td>
<td>3.0 (60%)</td>
<td>4.0 (67%)</td>
<td>4.0 (67%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CINS</td>
<td>5</td>
<td>13</td>
<td>-</td>
<td>Reflection Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEB</td>
<td>4.40</td>
<td>4.75</td>
<td>-</td>
<td>High 9/11 (SB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMQII</td>
<td>4.60</td>
<td>4.55</td>
<td>-</td>
<td>High 6/7 (SM)</td>
<td></td>
</tr>
<tr>
<td>Paige (E)</td>
<td>Concept Map</td>
<td>18.0</td>
<td>18.0</td>
<td>37.0</td>
<td>Direct Ontology</td>
<td>1. Proximate</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td>2. Proximate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proposition</td>
<td>1.2 (5)</td>
<td>1.3 (3)</td>
<td>2.2 (8)</td>
<td>3. Proximate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>15.0</td>
<td>14.0</td>
<td>17.0</td>
<td>4. Proximate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolutionary</td>
<td>3.0 (60%)</td>
<td>3.0 (100%)</td>
<td>7.0 (88%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CINS</td>
<td>5</td>
<td>10</td>
<td>-</td>
<td>Reflection Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEB</td>
<td>4.04</td>
<td>4.75</td>
<td>-</td>
<td>High 8/11 (SB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMQII</td>
<td>2.80</td>
<td>3.52</td>
<td>-</td>
<td>High 5/7 (SM)</td>
<td></td>
</tr>
<tr>
<td>Zena (E)</td>
<td>Concept Map</td>
<td>18.0</td>
<td>42.0</td>
<td>31.0</td>
<td>Direct Ontology</td>
<td>1. Evolutionary</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td>2. Evolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proposition</td>
<td>1.6 (2)</td>
<td>1.8 (10)</td>
<td>2.6 (9)</td>
<td>3. Evolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>11.0</td>
<td>23.0</td>
<td>12.0</td>
<td>4. Evolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolutionary</td>
<td>0.0 (0%)</td>
<td>7.0 (70%)</td>
<td>7.0 (78%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CINS</td>
<td>7</td>
<td>10</td>
<td>-</td>
<td>Reflection Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEB</td>
<td>4.23</td>
<td>4.19</td>
<td>-</td>
<td>High 7/11 (SB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMQII</td>
<td>4.44</td>
<td>4.35</td>
<td>-</td>
<td>High 7/7 (SM)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: (E)= ECO+E/experimental group; (SB)=science beliefs; (SM)=science motivations; Parentheses = (number of 3 scores); (percent of evolutionary propositions); Student names are pseudo-names.
## Appendix C5: Synthesis of Individual ECO Results

### Table C5

*Individual Summary of Student Data from Assessments and Reflections (ECO)*

<table>
<thead>
<tr>
<th>Student</th>
<th>Test</th>
<th>Pre-Test Scores</th>
<th>Post-Test Final Scores</th>
<th>Suppositions Tasks/Reflections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chris (C)</td>
<td>Concept Map</td>
<td>Accuracy 15.0</td>
<td>24.0</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proposition 1.7 (2)</td>
<td>1.9 (4)</td>
<td>2.0 (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 9.0</td>
<td>13.0</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolutionary 1.0 (50%)</td>
<td>3.0 (75%)</td>
<td>3.0 (75%)</td>
</tr>
<tr>
<td></td>
<td>CINS 6</td>
<td>14</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SEB 4.45</td>
<td>4.27</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SMQII 3.18</td>
<td>3.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Don (C)</td>
<td>Concept Map</td>
<td>Accuracy 27.0</td>
<td>22.0</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proposition 2.1 (5)</td>
<td>1.4 (2)</td>
<td>1.8 (6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 13.0</td>
<td>16.0</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolutionary 4.0 (80%)</td>
<td>1.0 (50%)</td>
<td>5.0 (100%)</td>
</tr>
<tr>
<td></td>
<td>CINS 8</td>
<td>12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SEB 3.84</td>
<td>4.34</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SMQII 2.23</td>
<td>2.41</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kevin (C)</td>
<td>Concept Map</td>
<td>Accuracy 23.0</td>
<td>31.0</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proposition 2.1 (6)</td>
<td>1.7 (4)</td>
<td>2.1 (9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 11.0</td>
<td>18.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolutionary 4.0 (67%)</td>
<td>4.0 (100%)</td>
<td>6.0 (67%)</td>
</tr>
<tr>
<td></td>
<td>CINS 9</td>
<td>11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SEB 4.21</td>
<td>4.36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SMQII 4.21</td>
<td>3.91</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lisa (C)</td>
<td>Concept Map</td>
<td>Accuracy 14.0</td>
<td>29.0</td>
<td>27.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proposition 1.6 (3)</td>
<td>1.6 (3)</td>
<td>1.6 (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 9.0</td>
<td>18.0</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolutionary 3.0 (100%)</td>
<td>1.0 (33%)</td>
<td>4.0 (100%)</td>
</tr>
<tr>
<td></td>
<td>CINS 7</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SEB 4.38</td>
<td>4.54</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SMQII 2.99</td>
<td>2.72</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mike (C)</td>
<td>Concept Map</td>
<td>Accuracy 28.0</td>
<td>45.0</td>
<td>46.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proposition 2.3 (6)</td>
<td>2.0 (13)</td>
<td>2.3 (13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 12.0</td>
<td>22.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolutionary 5.0 (83%)</td>
<td>11.0 (85%)</td>
<td>10.0 (77%)</td>
</tr>
<tr>
<td></td>
<td>CINS 10</td>
<td>13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SEB 4.07</td>
<td>4.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SMQII 3.36</td>
<td>3.36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stuart (C)</td>
<td>Concept Map</td>
<td>Accuracy 28.0</td>
<td>47.0</td>
<td>46.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proposition 2.3 (7)</td>
<td>2.0 (10)</td>
<td>2.4 (13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 12.0</td>
<td>24.0</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolutionary 4.0 (57%)</td>
<td>6.0 (60%)</td>
<td>7.0 (54%)</td>
</tr>
<tr>
<td></td>
<td>CINS 6</td>
<td>9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SEB 3.53</td>
<td>3.97</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SMQII 3.52</td>
<td>3.96</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes: (C)= ECO/control group; (SB)=science beliefs; (SM)=science motivations; Parentheses = (number of 3 scores); (percent of evolutionary propositions); Student names are pseudo-names.