Factors Influencing Conceptual Change in Evolution: A Longitudinal, Multicase Study.

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Factors influencing conceptual change in evolution: A longitudinal, multicase study

Demastes, Sherry Southerland, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1994
FACTORS INFLUENCING CONCEPTUAL CHANGE IN EVOLUTION: 
A LONGITUDINAL, MULTICASE STUDY 

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Agricultural and Mechanical College 
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in 
The Department of Curriculum and Instruction 

by 
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May 1994
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ABSTRACT

A high school Biology II classroom was observed daily in order to study students' conceptual change in evolution of life. The conceptual frameworks of four student participants were documented and the patterns of conceptual change were studied closely throughout the full school year. Data collected included open-ended and structured individual interviews, student journals, daily classroom observations, field notes, and pre- and posttests. All 68 student interviews (17 per student) were recorded, transcribed, coded, and sorted to find patterns of conceptual change. Additional interviews were conducted with the teacher, parents, principal, and high school counselor. The researchers' interpretations were shared with the student participants and teacher to ensure that the voices of all research participants were heard.

The finding of this multi-case study of conceptual change include:

1. Conceptual change about evolution of life can occur in one of three patterns: (a) holistic, (b) fragmented and gradual, and (c) dual constructions.

2. Conceptual change can occur with little corresponding change in belief. The Darwinian theory of the evolution of life, in its modern form, can be understood but not accepted.

3. The most influential factor inhibiting conceptual change toward a more scientific framework is not belief, but the learner's feelings of disturbance and conflict as learning occurs.

4. Certain critical issues, called threshold questions, in this study, seem to be central to conceptual change. An example threshold question is "How could two different species stem from one original species?"

5. Conceptual change is often based upon the idiosyncratic, extra-logical assessment of competing conceptions.

6. Often, the change of one conception allows a sequence of changes to occur in the learner's overall conceptual framework. Overall, this study demonstrates
that many conceptions in this area are closely interwoven, so that a change in
one conception requires a gradual blending and modification of related
conceptions.

7. The actions of a learner's conceptual ecology are found to vary with each
individual. The participant's orientation toward academic work,
epistemological approach to scientific knowledge, belief in evolutionary
theory, and approach to scientific topics play integrated roles in controlling
the learning that may occur.
CHAPTER 1
INTRODUCTION

A student sitting in a biology class in rural Louisiana asks his teacher what he perceives to be a simple question, "Tell me about alligators." The teacher stops and looks out the classroom window furrowing her brows in puzzlement. What should she tell the student? Should the question be approached taxonomically, and the student informed about the classification of the alligator as both a vertebrate and a reptile? Should the question be approached physiologically, and the student informed about the unique cardiovascular structure of the alligator? Or should a reproductive approach be used, with an explanation of the evidence for maternal care shown by these unique reptiles and the insight this may provide a paleontologist in her studies of dinosaur artifacts? Given much reflection, the responses stretch out endlessly. The student shakes his head muttering that the teacher is daydreaming.

In his collection of essays entitled Toward a New Philosophy of Biology, Mayr (1988) eloquently describes the cause of the teacher's bemusement. Biology is an inherently complex science. This complexity stems from the multiple layers of explanation made possible by very different disciplines which exist under the umbrella of biology. Reproductive biology, taxonomy, physiology, ethology, anatomy, ecology--these disciplines represent a small fraction of the many theoretical frames studied by biologists. Faced with this fragmentation and complexity, it is not surprising that a layperson approaching this field resorts to rote lists as a means of acquiring a small fraction of knowledge. Unfortunately, such knowledge usually remains isolated and fragmented as the student is unsuccessful in constructing links between diverse knowledge claims. For such a student, biology is seen as a body of established facts to be learned in class, having little application to the natural world. As has been argued by a host of biologists (Dobzhansky, 1973; Mayr, 1976, 1988) and science educators (Cummins & Remsin, 1992; Good et al., 1992; Settlage, in press), the theoretical
framework provided by evolution provides a means of tying together the many disciplines found in biology to form a single, coherent, and fluid science. The respected geneticist and theorist Dobzhansky aptly described the importance of the evolutionary theory in his now-famous quote, "Nothing in biology makes sense except in the light of evolution" (1973, p. 125). Biologists and biology educators think the understanding of evolution is crucial for a student to synthesize and integrate diverse biological concepts.

It is widely recognized that the manner in which we teach science is in need of revision. In 1989, the American Association for the Advancement of Science suggested that the goal of science educators should be the preparation of scientifically literate students. Literacy in a science involves an understanding of a core of all-pervasive principles of that discipline and the ability to apply these principles in situations in and out of the science classroom (Wandersee, 1991). The core principles of biology include information (genetics), energy flow, organisms, and evolution (AAAS, 1989). Thus, a biologically literate student is one who can apply these core concepts in the consideration of any biological topic.

Unfortunately, despite the recognition of the importance of evolution in the goal of biological literacy, Shankar and Skogg (1993) suggest that biology teachers do not emphasize this topic in their classes and many even avoid mention of this unifying theory. This core principle of biology is not being adequately taught in our nation's schools. While my past work has investigated the means through which instruction can be changed and directed to achieve the goal of biological literacy (Demastes & Wandersee, 1990), this study has a different focus. Given that a thorough understanding of evolution is necessary in order to be biological literate, how does such understanding come about? The purpose of this study is to investigate the manner in which students construct a conceptual framework for the theory of evolution.

Many science educators now understand learning to involve the active restructuring of knowledge (Duschl & Gitomer, 1991). The conceptual change theory of
Posner, Strike, Hewson, and Gertzog (1982) represents an attempt to model this restructuring process. This theory uses the model of Kuhn's (1970) scientific revolution as a basis for understanding the process of holistic conceptual change within the learner. Conceptual change is understood to be directed by the learner's rational evaluation of the new conception. Additionally, the learner's conceptual ecology (Toulmin, 1972), a fundamentally organizing system of conceptions, is said to influence the change that occurs.

Smith, Blakeslee, and Anderson (1993) explain that meaningful learning entails the construction or reconstruction of a conceptual framework for a topic. A conceptual framework includes all of the interlinked conceptions a learner has about a particular topic. Thus, all new information is understood by the learner in terms of her/his pre-existing, overarching conceptual framework. In this theoretical framework, conceptual change is seen as the structural adjustments the learner makes to the overarching conceptual framework based upon new experiences, information, or concepts the learner encounters. Unlike rote learning, the meaningful learning which results from conceptual change will allow the learner to not only recall information, but also to describe, predict, and explain natural occurrences (Smith et al., 1993). Using this understanding, how can we measure if conceptual change has occurred? It would seem that simple information questions would not provide educators an adequate measure. Instead students should be asked to describe, predict, and explain natural situations.

I selected the conceptual change theory because of its fruitfulness as a model of the learning of major, organizing conceptions, and I perceive evolution to be such a conception. However, as a theoretical base, the conceptual change theory is also in need of further refinement, modification, and validation as has been suggested by Strike and Posner (1992). Therefore, the overall purpose of this work is twofold: to understand how students construct a conceptual framework and to determine the particularities of
this construction when evolution is the content investigated. (See Figure 1 for a summary of the research.)

Research Questions

The research questions of this study include:

1. What is the nature of the process of conceptual change of evolution?
2. What factors facilitate or prohibit conceptual change?
3. What is the nature of the interface between students' conceptual frameworks in evolution and their conceptual ecologies?
4. What are the limits of the conceptual change theory in the description of conceptual change in evolution?

Definitions

For the purposes of the study, the following definitions will be used:

1. Belief will be defined in its relationship to understanding. Belief and understanding are both forms of knowledge which may overlap. But when these two types of knowledge differ, understanding includes knowledge which has an academic component, and belief includes knowledge which is taken on faith in a supernatural agent (Pajares, 1992).
2. Belief system is a set of organized and interconnected individual beliefs.
3. Biological evolution is a theoretical framework which describes the various processes which can lead to the genetic change in a population of organisms over time.
4. Classroom discussion refers to any formal or informal oral treatment of a topic by more than two participants.
5. Reflexivity in research refers to the actions of the research participants changing the methods and analysis of the research as well as the actions of the research/researcher changing some state of the participants.
RESEARCH QUESTIONS

What is the nature of the process of conceptual change in evolution?

What factors facilitate or prohibit conceptual change?

What is the nature of the interface between conceptual frameworks and conceptual ecologies?

What are the limits of the conceptual change theory in describing conceptual change in evolution?

World View
Nature is observable and knowable.
Science is one way of knowing the world (Moore).
Human knowledge is tentative and subject to change.

Theories
Biological evolution
Conceptual change theory (Posner et al.)
Grounded theory
Alternative conceptions

Principles
• Think aloud interviewing, in-depth interviewing, structured interviewing, and mode validity are qualitative research techniques
• Variable species, selection pressure, and mutation are aspects of evolutionary theory
• Conceptual change theory (Posner et al.) requires learner's perception of intelligibility, plausibility, and fruitfulness of the new conception

Value Claims
Current conceptual change theory is limited in scope:
New descriptions of actual patterns of conceptual change should be made for other content areas:
High school students can learn evolutionary theory:
Belief does not assure or prohibit understanding

Knowledge claims
Conceptual change in evolution follows wholesale, gradual, and dual patterns:
Reading, integrated instruction, and interviews facilitate conceptual change:
Different aspects of conceptual ecologies control conceptual change

Data Transformations
Interview transcription, coding, and analysis:
C-map analysis: Categorization of student's pre and posttest exam responses: Comparisons of interview participants' exam with whole class exam

Record
Audio and video tape of interview: Field notes and field journal of interviews and observations: Pre and posttest responses: C-maps

Events
Participant's self-descriptions: Participant's analysis of evolutionary and genetic events:
Responses to pretest and posttest questions and explanations of answers: Oral and written responses to interview questions: Instruction in evolution: Participant observation

Figure 1
Gowin's vee of research
CHAPTER 2
LITERATURE REVIEW

Theoretical Base

Constructivism

Constructivism is understood to be a model of learning by some science educators and a doctrine of education by others (Suchting, 1992). Constructivism involves the construction of meaning by an active learner as newly formed concepts are connected to the learner's prior knowledge in an attempt to understand her/his world. The foundational understanding is that learners construct their knowledge from experience with the world, with individuals, and within cultures. The child as an active participant in construction of her/his own learning radically differs from the behaviorist approach which proposes the learner as a relatively passive receiver of information.

This is a very broad description, requiring constructivism to serve as the basis for a wide range of theories. This range was the focus of Cobern's (1991) description of the emergence of the constructivist movement within science education. In Cobern's account, constructivism can be divided into personal and contextual categories.

Cobern (1991) traces personal constructivism as an initial branch from Piaget's work. This theory focuses on the actions of the learner during knowledge construction. Cobern states that research using personal constructivism centers around the actual construction process used by the learner. It asks: How does the learner construct knowledge? One mechanism by which personal constructivism can be carried out is that described by the conceptual change theory. This theory of learning forms the basis for the my proposed research.

A second category Cobern names in his analysis of constructivist research is contextual constructivism. Contextual constructivism is bifocal; the focus is not solely on the student's knowledge construction, but also on how that construction is affected by
the learner's life situation. It asks: What is the social contribution to learning? Learning is analyzed within the cultural context of the learner. Contextual constructivism also influenced my research as I observed the participants in their classroom and as I studied the influences behind the teaching which was carried on in this classroom. These activities were carried out in an effort to understand the process through which learning is negotiated within the Laboratory School setting.

**Conceptual Change Theory**

The proposed research also draws on the theory of conceptual change as proposed by Posner et al. (1982). The authors view their theory as describing the methods by which conceptual frameworks are constructed and modified. More narrowly, the conceptual change theory describes the process by which a learner captures new concepts, restructures existing concepts, or exchanges concepts from one set to another. This theory uses the model of scientific theory construction as a basis for understanding the process of conceptual change within the learner. This theory deals primarily with central, organizing concepts, and explains that conceptual change can be elicited when learners recognize the shortcomings of their present understanding and are shown a more intelligible, plausible, and fruitful alternative. Within this model, the learner's conceptual ecology is of fundamental importance in controlling the process of conceptual change. This ecology, as described by Toulmin (1972), includes the learner's epistemological commitments, metaphysical beliefs, and knowledge outside the field. In their original description (Posner et al., 1982), the actions of the learner's conceptual ecology are, at best, ambiguous. Aspects of my research represent an attempt to define the actions of the conceptual ecology on the process of conceptual change.

The conceptual change theory as it defines the growth of one learner's conception is situated within the constructivist theoretical basis, initially extending from personal constructivism. Despite its genealogy, contextual constructivism may eventually have important insights for the conceptual change theory, introducing the impact of affective,
linguistic, and social domains in the production of conceptual change. Such an introduction may serve to make the conceptual change theory a more descriptive theory of learning.

Alternative Conceptions

The conceptual change theory emphasizes the importance of students' prior knowledge in instruction decision making and implementation. Such emphasis was begun with the work of Ausubel (1968) with his emphasis of prior knowledge in the process of learning, and was continued by Driver and Easley (1978). This foundation helped science education change from its exclusive focus on learners' cognitive and logical structures to examining the content of learners' understandings. In recent decades, investigations into students' prior knowledge have flourished. Wandersee, Mintzes and Novak (in press) have identified 2,400 such studies in the field of science education.

One obvious difficulty seen as a reader approaches this field is the tremendous diversity of terms currently used in science education to describe students' prior knowledge. These terms include misconceptions, alternative conceptions, prescientific conceptions, naive conceptions, children's science, and intuitive beliefs (Hills, 1989). As mentioned earlier, each term implies a slightly different epistemological base. Both Good (1991) and Wandersee et al. (in press) express the need for a convergence in terms within this area. The historically prominent and popular term, misconception, implies that there is little heuristic value to students' conceptions and suggests that they exist simply as something to be corrected. The importance conceptual change theory places on students' knowledge precludes this choice. Good (1991) has suggested the term prescientific conceptions because this term applies only to science, is appropriate to both adults and children, and avoids the negative connotation of misconception while conveying the extra-scientific nature of the conception. Unfortunately, prescientific
conceptions, cannot reasonably be used to refer to conceptions constructed within a science classroom. Therefore, this term is potentially very restrictive.

In a similar vein, in their review of research in this area, Wandersee et al. (in press) suggest use of the term alternative conceptions, justifying this choice based both on its prominence in the literature and on its tacit meanings. Alternative conception implies an experience and contextually based, rational explanation. The authors explain that such a term potentially provides for more intellectual respect for the students' learning and represents an attempt to better understand students' views and their intellectual difficulties. In an extension, while alternative conception describes students' understanding of a concept, alternative framework refers to a complex organization of linked conceptions.

The issue of terminology for the understandings students have of scientific phenomena remains unresolved. For the purposes of this study, terms which signify a lack of emphasis on the instructional power of these conceptions will not be used. Instead, alternative conceptions will be used because of the broad meaning embedded in the term and its reference to the heuristic nature of students' conceptions.

Findings from a survey of experts in the field of alternative conceptions suggest that science education should integrate studies within a content area, and the field should move forward to descriptions of conceptual change. Additionally, these experts explain that an understanding of the cultural dimensions of students' conceptions is now required (Wandersee et al., in press). This proposed research will follow both suggested pathways.

Studies on the Learning of Evolution

Mayr (1976) described six world views that were widely held by scientific circles before Darwin's theory of evolution by natural selection (1859). The conceptions restructured by the requirements of Darwin's theory included: (a) a young earth, (b) an earth undergoing both catastrophes and long periods of no change, (c) teleological
change, (d) creationism, (e) view of species as individuals without variation (essentialism), and (f) anthropocentrism. While many of the original conceptions were undergoing significant changes before Darwin's work, the formulation and acceptance of the theory of evolution by natural selection eventually forced a widespread restructuring and acceptance of different conceptions within the scientific community. The theory of evolution as mechanized by natural selection requires conceptions of: a) an old earth, b) an earth undergoing gradual changes, c) change of a species through origin in a random occurrence acted on by natural selection, d) common descent of organisms, e) a view of species as a collection of variable individuals, and f) a view of humans as existing within the biological realm. These modified conceptions are necessary components of a scientific understanding of evolution and have been the focus of much of the research done in students' understandings of evolution.

Facets of Students' Conceptions of Evolution

Adaptation

The conception of adaptation is one facet of a scientific understanding of evolution. However, Lucas (1971) describes that the term adaptation can have several meanings in biology, which often are not well articulated to students. Lucas explains that adaptation can refer to immediate physiological changes in an individual, to characteristics of an organism which suit it to the environment, and also to the process in which a population is modified to greater fitness with respect to its environment. Rarely do students have this metaknowledge, and so cannot differentiate between the various uses of the word adaptation. Lucas' ideas (1971) are supported by the work of Kargbo, Hobbs, and Erickson (1980) who explained that the students studied (ages 7-13) often do not distinguish between non-heritable characteristics which are adaptive and characteristics which are inherited in a population. The high school students in studies by Renner, Brumby, and Shepherd (1981) and Halldén (1988), as well as medical students in a study by Brumby (1984), used adaptation in an individual sense of
proximate change in response to environmental changes. Earlier work by Brumby (1979) demonstrated that medical students understood adaptation as a positive process resulting from need rather than the end-result of a selection event.

Clough and Wood-Robinson (1985b) attempted to identify common belief patterns of 12-16 year old students in the area of biological adaptation. Developmental changes of students in the study were addressed by repeating the interview two years after the initial encounter. This study documented an increase in the number of older students who held a scientific conception of adaptation. The authors attributed this improvement to both teaching and students' development. However, the study further supports the description of adaptation as a difficult area in the study of biology and documents a very strong trend toward teleological explanations of adaptation. Students viewed adaptations as caused by some purpose or design. Anthropomorphic explanations were also given as the cause of many adaptations. In these cases adaptations were cited as a conscious and deliberate response to need. The authors emphasized that such anthropomorphic expressions may reflect semantic difficulties, instead of difficulties in the underlying meaning. Finally, Clough and Wood-Robinson (1985b) stressed that students seldom make links between intraspecific variation and natural selection.

The research cited above is important in that the understanding students have of adaptation is central to their overall conception of evolution (Deadman & Kelly, 1978). In fact, many students use adaptation as their sole explanation of evolution (Halldén, 1988). While it is difficult to establish a causal relationship between the various facets of evolutionary thought, the findings of Bishop and Anderson (1990), Greene (1990), and Demastes, Good, Sundberg, and Dini (1992) show that the use of only a rapid form of adaptation undergone by an individual will have serious ramifications for other portions of the students' understandings of evolution.
**Time Frame**

Another facet of current evolutionary thought is the time interval in which evolution occurs. This was explored in a study by Renner, Brumby, and Shepherd (1981). In this study, the high school students studied could not differentiate between a 2 million year and a 200 million year time span, two radically different time periods. Other findings included: less than 5% of the students had an adequate grasp of evolution and could provide an adequate explanation for extinction, 44% attributed the death of the dinosaurs to proximal causes of water and food loss, and adaptation by the dinosaurs was seen as a rapid change of an individual caused by a changing environment.

**Teleology and Anthropomorphism**

One of the world views undermined by Darwin, and one that hinders a construction of a scientific understanding of evolution, is that of teleology. The most common usage of teleology in relation to biological understandings is that of evolution being directed to an end or shaped by an ultimate purpose. In his investigation of teleological explanations in biology, Jungwirth (1975a) found that even agricultural majors in the third year of their university education used teleological explanations of evolutionary phenomena on a multiple choice exam. This finding is supported by other researchers (Clough and Wood-Robinson, 1985b; Lawson & Weser, 1990). However, Halldén (1988) reminds us that such statements are difficult to analyze from written explanations.

Through highlights of debates between science educators and philosophers of science, Jungwirth (1975b) pointed out that the issue of teleology is not a straightforward one for educators. He described the close relationships between anthropomorphic and teleological explanations and between functional and teleological interpretations. Jungwirth (1975b) explained that teleological explanations are common in biology teaching because of their value as heuristic devices. This is supported by Halldén (1988) who reports that intentionality is often seen in biology textbooks.
While his earlier work suggested teleology and anthropomorphism as a problem created by poor teacher education, Jungwirth (1977) provided empirical support for this suggestion through comparisons of science education researchers, scientists, teachers, and preservice teachers. Science education researchers found teleological and anthropomorphic statements to be undesirable for study by biology students, while the teachers and scientists were less aware of the dangers of such statements. Preservice teachers were absolutely unaware of the existence of the problems of teleological and anthropomorphic statements. Each group had difficulties in distinguishing between these two types of statements.

One of the most comprehensive studies of teleology and anthropomorphism is found in the work of Tamir and Zohar (1991). In this research, shortcomings of the previous studies were remedied through the use of individual interviews with the 15-17 year old students studied. The authors determined that 30% of the students understood plants in anthropomorphic terms while 62% of the students understood animals in a similar manner. A higher majority, 71%, used teleological reasoning with respect to evolution. The authors explained that nonteleological statements were typically combined with a rejection of anthropomorphism, and teleological explanations were used to express a functional understanding of organism.

Teleology differs from many of the other conceptions discussed in that it could be more applicable to many other situations than other aspects of the individual's declarative knowledge. Teleology may have a great impact upon the construction of a scientific conception of evolution. This is a hypothesis that has yet to be supported or refuted by empirical evidence. My study attempted to explore through the use of student explanations teleology's function in students' construction of an evolutionary framework.
Genetics

The logical structure of the discipline of biology would indicate that an understanding of evolution is based on an understanding of genetics. There have been a number of studies which investigated students' conceptions of genetics. An early study based on interviews by Kargbo et al. (1980) indicated that a majority of the students, regardless of age, understood that all environmentally induced characteristics are heritable. The authors concluded that students' conceptions did not follow a developmental pathway, but altered according to their experiences. However, conceptions of probability regarding phenotypes of offspring were said to improve with the age of the students. The authors suggested that children develop two conceptual frameworks regarding inheritance, one constructed in school, and the other constructed in the course of everyday experiences. In novel situations, the students often use the latter structure for understanding.

In a later study of students' conceptions of inheritance, Clough and Wood-Robinson (1985a) used interviews involving prediction, explanation, and follow-up questions. The researchers found that many first-year, secondary school students have extensive conceptions of inheritance although they have not yet studied the subject. Students in the study typically discussed the biological phenomenon on a phenotypic level, excluding genetic explanations. Students viewed the timing of fertilization as determining inherited features and equated genetic dominance with phenotypic characters. Of most importance to conceptions of evolution, students viewed variation within populations as stemming from developmental defects. Between 40% and 50% of the students throughout the age range understood phenotypic changes as heritable.

Albaladejo and Lucas (1988) explained that the concept of mutation is fundamental in both genetics and evolution. They describe the English use of mutation as a technical term, while in the Catalan language, "mutacio" (mutation) has a wider usage, including any sudden change. Albaladejo and Lucas (1988) determined that in
Catalan, mutation is associated with many types of change, including puberty and metamorphosis.

Demastes et al. (1992) suggested that students' understandings of Mendelian genetics often fail to help them understand evolution. This echoes an earlier finding by Halldén (1988) who explained that instruction into Mendelian genetics does not provide a means of understanding evolution's mechanisms. Like Clough and Wood-Robinson (1985a), Demastes et al. (1992) documented a failure by university students to incorporate genetics into explanations of how populations of organisms change, even though instruction into genetics lead the unit on evolution. Such an omission was partially explained by Longden (1982). Using in-depth interviews with high school students having difficulties in genetics, Longden (1982) found two factors which inhibited understanding: (a) the precision of the language of genetics coupled with less than explicit teaching techniques into this language, and (b) the use of symbolic representation and mathematics. He suggested that students are involved only with the surface mechanics of genetics and so fail to understand the underlying significance of the process.

The research demonstrates that students have well-developed conceptions of inheritance which are formed from their out-of-school experiences. These conceptions invariably conflict with scientific conceptions and are often used by students to understand the world. Logically, one would think that a scientific conception of genetics is fundamental to a construction of a scientific conception of evolution, a judgment which guides the sequence of instruction in a large number of classrooms. Again, this logical assessment is not well supported by the research. The position of genetics in the student's conceptual ecology and its impact on an understanding of evolution need to be addressed.
Natural Selection

Several studies have focused on students' conceptions of one mechanism of evolution, natural selection. Brumby's work (1984) explored university students' conceptions of natural selection at the university level using both written questions and structured interviews. The results of the Brumby study demonstrate that students proficient in science leave school using the Lamarckian view of evolution; that is, evolution occurs because of need. Brumby (1984) explained that many students describe adaptation as a loss of function through disuse. Others see a change as affected by the environment, with change gradually unfolding in the offspring. Brumby (1984) reported that students confused the various biological meanings of adaptation by failing to distinguish between those changes within the individual and those changes seen in a population. This was described as "intuitive Lamarckism" (p. 499), and the author explained that this conception was far more than a simple error to be corrected. After the course in biology, these medical students still had their intuitive misconceptions, coupled with a poor ability to communicate their conceptions about natural selection. These results are supported by earlier work with a similar group of students (Brumby, 1979). Only 18% of these first year medical students who had previously studied biology could correctly apply a process of selection to an example of evolutionary change.

Summary

Students' alternative conceptions regarding the mechanisms of evolutionary change (i.e., genetics, adaptation, mutation) have been the most well studied aspect of evolution education. Many of these studies concentrated on a small facet of the entire conceptual framework for evolution. However, no single study has attempted to integrate these diverse findings in an attempt to understand the process through which related conceptions are constructed. One of the purposes of my research is to integrate these findings in order to better understand the process of conceptual change.
Entire Frameworks

Another avenue to understanding students' conceptions is to look at the students' conceptual framework for the whole of evolution, instead of focusing on a single facet of evolutionary thought. Such a general approach has the potential for providing a means of integration of previous research. An early example of this approach is seen in the work of Deadman and Kelly (1978). Longitudinal interviews were completed with boys ranging from 11 to 14 years of age. The interviews explored the students' understanding of evolution and heredity in a variety of contexts. The data from these interviews were used to provide a description of the students' alternative conceptions of the various facets of evolution.

Deadman and Kelly (1978) explain that the students in this study typically associated evolution with primitive life forms, but they did not use evolution to establish relationships between different taxa of organisms. Adaptation was central to all the boys' explanations of evolution. However, it is interesting to note that the students explained that evolution was driven by naturalistic forces (driven by the needs or wants of the animals) or environmentalistic forces (driven by physical changes in the environment). None of the boys had a sound understanding of natural selection, and the concept of chance rarely was prominent in their explanations. Deadman and Kelly (1978) concluded by stating the major difficulties in teaching evolution lie in the students' naturalistic and Lamarckian interpretations and their inadequate understanding of probability. Such conclusions may be unnecessarily pessimistic. The importance of early research in the broad topic of evolution is the identification of areas for further investigation (conceptions of adaptation, natural selection, chance). But in these early studies, extensive interpretation is not possible, as little supporting research evidence exists. For these reasons, the Deadman and Kelly (1978) study is an important initial investigation into students' conceptual frameworks of evolution, but the conclusions were premature.
In a later investigation of students' conceptions of evolution, Hallden (1988) used participant observations and verbal and written responses to assess high school students' conceptions during instruction in genetics and evolution. She determined that it was difficult to differentiate essays written before and after instruction, but upon close examination, more students did use a Darwinian explanation of evolution after instruction. However, students offered these explanations along with other nonscientific explanations. Hallden (1988) suggested that, instead of changing their conceptions, students simply added another possible explanation to their repertoires. Students failed to make a clear distinction between the individual and the species, therefore their use of adaptation was ambiguous. Adaptation was used to explain virtually all evolution, and single individuals were said to become better and better adapted. For these students, individual adaptation was synonymous with species adaptation, and students showed little understanding of variation within a species. Hallden (1988) further explained that students found the instruction they received to be disjointed and fragmentary, in contrast to the logical progression viewed by the researcher. The possibility of this discrepancy was suggested earlier by Driver (1981) when she reminded us that the logical order of a topic may not correspond to the psychological order of learning.

The Hallden (1988) study has important theoretical implications for the theory of conceptual change. In this study, the author reports that students formed new conceptual frameworks for evolution, but retained their former conceptions as well. Such information becomes important as science education researchers attempt to describe the process of conceptual change. Instead of a radical restructuring of presently existing conceptual frameworks, the learner may construct alternative conceptions. Holland, Holyoak, Nisbett, and Thagard (1986) suggest a default hierarchy model of cognition to explain these alternative conceptions and how they are selected for use within a context.

The findings of Greene (1990) are not so much a description of the components of students' conceptual frameworks of evolution, but more a description of how their
conceptions are related. The focus of this study was to determine if university students' written explanations follow a logical progression: not if their conceptions had a logical basis, but if their conceptions had logical relations. The four conceptual issues analyzed included (a) the use of a population or typological focus, (b) the use of an open or closed change process, (c) the generation of one or many traits, and (d) the use of a selection process. By a statistical analysis of the interaction of these three categories within students' answers, Greene (1990) found the alternative conceptions to be logical, if not conforming to current scientific thought. Students using a population focus employed a closed-change process, students viewing change as directed described little function for the selection process, and students using acquired traits did not use a functional idea of selection. While informative, the shortcomings of this study lie in the categorization of students' responses. The categories were constructed at the outset of the research and thereby limited what could be found during the course of the study.

In a related study, Settlage (in press) investigated alternative conceptions of evolution in an attempt to identify consistent patterns of conceptual change occurring during instruction. Using the Bishop and Anderson (1990) testing instrument (described in the following section), Settlage evaluated students' pre- and posttest conceptions of the mechanism of evolutionary change. In his analysis of examination responses of high school students, need was the most common response category identified. Variation in the population was the response category that underwent the greatest change; students' use of this category increased in frequency after instruction. The category of mutation also underwent an increase of only nine percent. This increase implies that the role of random mutation is accessible to students of this age but is not readily constructed. Students capable of this construction included those who had previously used the need or use category to explain evolutionary events. Settlage (in press) explained that students in his study understood evolution to be caused by deliberate intentions of the organisms,
although instruction did allow students to progress to a more scientific conception of evolution.

Summary

While the research of Halldén (1988), Greene (1990), and Settlage (in press) are informative, these studies fall short of actually helping researchers construct a better model for learning. This shortfall is due to their omission of a strong theoretical base. However, the findings of this holistic approach to the mechanism of evolutionary change did serve to shape my initial research methods and questions.

Conceptual Change Theory and Evolution

The work of Bishop and Anderson (1990) is one of the most important studies in the history of research into college students’ conceptions about natural selection. This importance stems from its position as one of the first pieces of research which investigated students’ conceptual frameworks, designed instructional materials to address students’ alternative conceptions, and then tested the effectiveness of such materials. The students were pretested, using an exam of both open-ended questions and multiple choice, during which the students were also asked about their belief in evolution and the extent of their prior coursework in biology. The students were then involved in instruction in natural selection. The teaching module used for this instruction was constructed from earlier investigations into students’ alternative conceptions concerning natural selection. This model was based on the theory of conceptual change and was designed to allow students to confront their misconceptions in order to build a more scientific understanding. After instruction, students were posttested to assess their conceptual change.

Bishop and Anderson (1990) identified three areas in which students’ conceptions of natural selection differed radically from those of biologists. The first issue was the origin and survival of new traits in populations. Students did not recognize the processes of increasing variation in genetic material and the process of
natural selection operating on that variation. Instead students described only one process by which individuals of a species change, a change caused by the environment. According to the students, the environment exerts its influence on variation through need, use and disuse, and adaptation. Bishop and Anderson (1990) explained that a major hindrance in the construction of a scientific conception is the inability to distinguish between the origin of a trait and selection upon that trait. Another issue described by students' alternative conceptions was the role of variation within a population. Students placed little importance on the role of variation among members of a population; instead, evolution was seen to be a change in a trait in a homogeneous population. The final issue of students' conceptions of natural selection concerned evolution as the changing proportion of individuals with discrete traits. Students viewed evolution as a gradual change in the traits themselves and not as an increase or decrease in the number of individuals in the population with such a trait.

While most of the students involved in the Bishop and Anderson (1990) study had completed at least one year of high school biology prior to the college course, this experience had little effect on students' alternative conceptions for any of the issues of natural selection. This study documents that university students have a poor understanding of how change in a population comes about, of the role of variation, or of evolution as genetically changing populations. After instruction, over half the students understood these ideas. From these results, Bishop and Anderson (1990) remind us that natural selection is far more difficult to understand than most instructors realize and that students can change their conceptions when their instructors are made aware of students' alternative conceptions and are prepared to confront them.

There have been several studies which built upon the base provided by the pioneering work of Bishop and Anderson (1990). The earliest of these derived works includes a set of replications carried out in order to focus on and define the limits of Bishop's and Anderson's findings (Demastes, Settlage, & Good, in press). These
authors were successful in replicating several of findings of the original study. These included: (a) a lack of an association between beliefs and students' abilities to construct a scientific conception during the course, (b) a lack of an association between the amount of prior instruction and students' abilities to construct a scientific conception during the course, and (c) a very meager movement toward the use of scientific conceptions for evolution during the course. However, the second component of this replication study did reveal significant increases in students' use of scientific conceptions. However, this second replication used a more prolonged instructional strategy than that employed by Bishop and Anderson (1990).

The report by Demastes and Good (1993) represents a second study which used the Bishop and Anderson (1990) instructional method and testing instrument. This study focused on the patterns of conceptual change experienced by college students during a nonmajor's biology course. These authors reported that three alternative conceptions were found to be held by a large segment of the students even after instruction. These included: (a) a typological species concept, (b) evolution as a change in all individuals in a population, and (c) the variation that is acted on by evolution is produced by need. Three patterns of conceptual change were documented in this study, including (a) movement toward the use of an scientific conception, (b) movement away from a scientific conception, and (c) movement between various alternative conceptions.

Demastes and Good suggest that the various patterns of conceptual change seen in this study lend support to Duschl's and Gitomer's (1991) criticism of the holistic process of conceptual change described by Posner et al. (1982). However, as will be discussed, Jiménez's (1992) work suggest that the process of conceptual change in evolution requires a very long time period. Therefore a major criticism of Demastes and Good (1993) is the relatively brief period (one semester) in which the process of conceptual change was studied.
The final study building on the work of Bishop and Anderson is that of Jensen and Finley (1993). Using the Bishop and Anderson (1990) testing instrument, these authors described and evaluated a new method of teaching the mechanism of evolutionary change. Termed an intervention, the authors devised instruction that recapitulated the events in the development of Darwin's theory of evolution by natural selection. While the instruction was not found to be very effective, the authors suggest that their instruction should have included events even earlier than Lamarck's ideas of evolution. Instead, Jensen and Finely argue, students' conceptions are more closely related to the work of Cuvier and Paley than the relatively sophisticated conceptions of Lamarck. A major source of criticism of this work and its interpretations involves the brief period of instruction and evaluation. Instruction for Jensen and Finely (1993) involved only one, two-hour laboratory period. The students' conception were evaluated with a pre- and posttest instrument administered over a three week time frame. The work of Jiménez suggests that this procedure introduces a very serious flaw into the work of Jensen and Finley (1993).

Informed by both the previous descriptions of alternative conceptions of evolution and the importance of reasoning ability within a specific content, Jiménez (1992) investigated the conditions necessary to promote conceptual change in evolution within the secondary school science classroom. She compared instruction which emphasized students' conceptions (the traditional group) with instruction which linked students' conceptions with Darwinian and Lamarckian interpretations (the experimental group).

Jiménez (1992) described many students' conceptions as relying on need. While the results of the groups did not vary on tests of declarative knowledge, students in the experimental group better differentiated between historical Darwinian and Lamarckian interpretations. Results from posttests administered one year after instruction demonstrated that students in the experimental group performed better on questions of
declarative knowledge and on questions requiring application of knowledge to a situation. For this study, Jiménez (1992) explained that explicit discussion of alternative conceptions and theories used in school science are necessary to augment conceptual change. Students need to be able to recognize differing interpretations of the same phenomenon in order to select the most plausible and fruitful conception.

**Summary**

The theory of conceptual change as proposed by Posner et al. (1982) has been demonstrated to be an intelligible one when applied to the construction of a scientific conception of evolution. It has been shown to be mildly effective as a theoretical base for instruction. This limited effectiveness may be more indicative of the nature of alternative conceptions in evolution than a reflection of the utility of the theory. Its application to this content area is in need for further exploration, as the results found in this area may be instructive for many other core concepts of the sciences.

The research base which joined conceptual change theory with evolution education played the greatest role in shaping my theoretical base, research questions, methods, study duration and goals. The findings of Bishop and Anderson (1990) revealed the usefulness of the conceptual change theory as it is applied to the process of learning evolution. At the same time, however, the questions left unanswered by their study shaped the initial focus of my work. Jiménez’s (1992) work made clear the expanded time frame required by investigations into conceptual change. Finally, while so much is revealed by these studies, there was a need to unify these findings. But such a study would require not only a longitudinal time frame, but also a very intensive focus, thus necessitating a limited number of participants. My research is an attempt to fill each of these requirements.
The Interaction of Conceptions of Evolution, Reasoning Ability, and Students' Belief Systems

Several researchers have attempted to isolate relationships between students' conceptual frameworks in evolution with other aspects of their intellectual lives. Most prominent in this vein is the work which attempts to correlate students' understanding to students' ability to reason. In one of the first such studies, Lawson and Thompson (1988) worked with a group of seventh grade students and determined that their nonscientific beliefs were significantly correlated to reasoning skill. All naïve students, despite reasoning ability, tended to adopt a theory of acquired characteristics. However, nonscientific beliefs of natural selection occurred more frequently in the students with poor reasoning ability after instruction. Lawson and Thompson (1988) explained that the students with poor reasoning ability did not reject nonscientific beliefs after instruction because they lacked skill with reasoning patterns necessary to do so. Students in the study were capable of using both scientific and alternative conceptions, the latter when phenomena were subtle, and the former when phenomena were explicit. Less skilled reasoners were said to retain nonscientific beliefs, such as a Lamarckian understanding of evolution, because they failed to examine alternatives and failed to fully comprehend conflicting evidence.

Lawson's and Weser's (1990) study of university students, while supporting the importance of reasoning ability, also included one of the most extensive analyses of nonscientific beliefs about life. The nonscientific beliefs examined included special creation, orthogenesis, presence of a soul, constitutive nonreductionism, vitalism, teleology, and nonemergentism. Lawson and Weser (1990) concluded that less skilled reasoners, as measured by the Classroom Test of Scientific Reasoning (Lawson, 1987), were more likely to hold nonscientific beliefs about life during the pretest, and showed the least modification during instruction. These less skilled reasoners were also described as being more likely to be only loosely committed to their belief structure.
The greatest significance of this study lies in the description of the students nonscientific beliefs about life. Approximately 40% of the students expressed an initial belief in evolution; belief in evolution was shown to increase during instruction. Thirty percent of the students at the outset agreed with conceptions of orthogenesis, 70-80% with vitalism, and 25% with a teleological expression. The course moved some students away from vitalism, making the students more mechanistic, but moved them toward orthogenesis.

A similar study was undertaken by Lawson and Worsnop (1992) with a group of high school biology students. The authors found that reflective reasoning skills were significantly related to initial scientific beliefs and to gains in declarative knowledge, but not to changes in beliefs. Prior declarative knowledge was not found to be associated with gains in declarative knowledge. Finally, the strength of religious commitment was negatively correlated with initial belief in evolution and with change in belief toward evolution. The instruction did not result in a group-wide shift toward a belief in evolution. The authors state that reflective reasoning skills operate in the "acquisition of domain specific knowledge" and that knowledge determines what one believes (p. 165).

This study is vulnerable to the same criticisms as those by Lawson and Thompson (1988) and Lawson and Weser (1990) because of the use of the Classroom Test of Scientific Reasoning (Lawson, 1987) to assess reasoning ability. With this test, learners who were labeled reflective reasoners used hypothetico-deductive reasoning to answer questions from a variety of contexts. These reasoning abilities are understood to operate in the same manner, regardless of the content. This assumption has failed to withstand investigation (Linn, Clement, & Pulos, 1983), and content is now a central issue in science education research (Linn, 1987). Because of the difficulties in assessing content-bound reasoning abilities, my present study does not include the issue of a student's reasoning skills in the construction of a conceptual framework for evolution. However, the work by Lawson and Worsnop (1992) does provide some insight into the
strength and importance of the students' belief structures in their understanding of evolution which was used to design my present research.

In an effort to refine earlier research in student reasoning, Cummins, Good, Demastes, and Peebles (in press) analyzed student reasoning in a specific content area: island biogeography. In interpretation of ambiguous biological data, students included variables of size, distance, and food availability as determining factors for the number of species found on various islands. Students in a twelfth grade class used the evolutionary concepts of adaptation, extinction, and speciation as much or more than students in a ninth grade class or students in a college zoology class. Students in the twelfth grade class used the concept of speciation as a variable far more extensively than the previous two groups by integrating their understanding of evolution in their evaluation of the evidence. This use of evolution as a variable is striking when one considers that the teacher of the twelfth grade class emphasized evolution throughout the year. From this, Cummins et al. (in press) concluded that reasoning within a biological content is improved by an increase in biological knowledge. Reasoning within the content area of evolution was found to be enhanced by biological instruction which used evolution as an organizing theme.

In an investigation of the relationship between students' use of scientific conceptions and their belief systems, Eve and Dunn (1990) found high levels of nonscientific and pseudoscientific beliefs in their study of high school biology and life science teachers. Like the works cited earlier, (Lawson & Thompson, 1988; Lawson & Weser, 1990), the authors explained this adherence to pseudoscientific beliefs, not based on religious or regional factors, but based on poor scientific reasoning abilities. Similarly, Eve and Harrold (1986) suggested that acceptance of pseudoscience occurs in individuals with limited abilities to examine evidence and generate hypotheses. This study found no statistical relationship between a student's use of a creationist explanation of biological diversity and the student's gender, parental level of education, or
rural/urban background. They did however find a strong relationship between religious conservatism and creationist belief. Both studies, while informative in providing a description of extrascientific belief structure, did not measure reasoning skills in this content area. Therefore, the authors association of reasoning ability to acceptance of evolution can be no more than speculation.

Grose and Simpson (1982) investigated the relationship of several variables with university students' attitudes toward evolution. They found that 54% believed in evolution, while 19% did not, and 22% were neutral toward the theory. Females scored significantly higher on a scale measuring attitudes toward evolution, with a significant interaction between gender, the influence of the high school biology teacher, and attitude toward evolution. This interaction was due to the influence of the teachers on the female students. The influence of the church was correlated inversely with attitude toward evolution, but there was no correlation between denominations and students' attitudes toward evolution. The biology majors did not score significantly higher than nonbiology majors. Because this was the first biology course for 80% of the college students, these results suggest that the students' attitudes toward evolution were formed prior to entering this course.

The interaction of students' ability to reason and their construction of a scientific conception of evolution has been the focus of many studies. Researchers in this area report that students who are better reasoners are more apt to hold a scientific conception in this area. Their conclusions should be considered, yet further studies in which reasoning is considered in the content area of evolution, or even biology, are required for a better understanding of this interaction.

Interactions of Students' Conceptions of Evolution and the Nature of Science

Because of the volatile nature of the subject of evolution in American society, many educators explain that the most appropriate means of introducing this topic is
through an understanding of the nature of science (Nelson, 1986; Scott, 1987). This position acknowledges the emotional concerns of instruction. Such a justification goes far in breaking the artificial dichotomy between cognitive and affective domains in learning.

In an Australian study of students' conceptions of the nature of science (Barnett, Brown, & Caton, 1983), a set of questions concerning evolution and the philosophy of biology were given to third and fourth year undergraduates and graduate students. Although all students were passing their biology courses, each performed poorly on written, open-ended tests. These students had a very poor, uncritical understanding of evolution; two thirds accepted natural selection uncritically, meaning they did not analyze the value of the knowledge claims supporting this theory. Other findings demonstrated that these students had a very poor understanding of biology as a science. A majority of the students understood physics and biology to be basically similar sciences, with half of the students explaining that all biological events could be reduced to physical science (Barnett et al., 1983).

Through the use of survey responses, Johnson and Peeples (1987) examined the relationships of students' understandings of the nature of science and their acceptance of evolution. The responses demonstrated that biology students had a weak understanding of the nature of science and were neutral in their acceptance of evolution as a valid scientific theory. Acceptance of evolution was found to be significantly related to understanding the nature of science. Understandings of the nature of science were poor, but did improve with grade level. The authors suggested that a comparison of the scope, nature, and goals of science would aid the student in discriminating between science and pseudoscience.

The work of Scharmann and Harris (1992) represents an effort to examine the effects of a diversified instructional strategy on teachers' understandings of evolution and the nature of science, as well as their attitudes toward evolution. The instructional
strategy tested was one that incorporated foundational content/context, allowed for student discussion, resolved conflicts arising in those discussions, and required a reflective summary of the course. The group involved in this instruction showed a significant increase in both their understanding of evolution and the applied nature of science. This was accompanied with an increased acceptance of evolutionary theory by the participants.

Scharmann and Harris (1992) confirms the earlier suggestion of Johnson and Peeples (1987) that an understanding of evolution can be associated with an understanding of the nature of science. However, the relationship of attitudes to achievement is still very unclear. The ability to differentiate between scientific ways of knowing and those of other realms may allow the student to relate knowledge of evolution to their belief framework, but this may not serve to lessen the difficulties students have constructing an scientific understanding in this area. Because of the emphasis I placed on understanding the action of the learner's conceptual ecology on the process of conceptual change, a large part of my study concentrated on the relationships between a learner's belief and academic understanding.

Complicating Factors in Descriptions of Students' Understandings

A great deal of the research carried out in the description of students' understandings relies heavily on written or verbal explanation of evolutionary occurrences. This trend may be in response to both the complicated nature of research into conceptual frameworks and the intricate nature of evolutionary thought. Such information is rich in detail and perhaps is a more effective way of providing an accurate description; however, such methods are not without their drawbacks. One such drawback lies in the nature of the discipline of biology. Biology is a science that requires multiple layers of explanation to identify causes. Proximal causes are those that occur during the life span of the organism and do not produce a change in genetic information.
Ultimate causes are those which do effect the genetic information of the species (Mayr, 1961, 1988).

Cummins and Remsen (1992) stated that university students have very little experience differentiating between proximal and ultimate levels of causation, and often the students view these explanations as being competing hypotheses. Explanations of proximate causes are much more frequent in students’ explanations. Why? Biology is unique among the sciences in having multiple levels of causality (Mayr, 1961, 1988). Even within biology, courses that stress biochemistry, cell structure, and physiology often deal only with proximal causality. Because of the thrust of much of their biology coursework and their experiences in other sciences, students have little or no experience with multiple levels of causality. In this situation, a student may answer a problem with a familiar proximate cause without considering the ultimate causality inherent in the problem. Work by Hauslein, Good, and Cummins (1992) determined that college students and teachers are less able to switch between levels of causality than scientists. Future research must be sensitive to this situation and probe farther to determine if the student has a poor understanding of evolution or if the student fails to recognize the necessity of responding to each of the levels of causality.
CHAPTER 3

METHODS

Rationale for Research Methods

The research questions should guide the choice of methods used in their investigation. The goals of my research included describing the process of students' conceptual change and achieving an understanding of how students come to understand evolution. These goals required that an ideographic approach be used. Such an approach involves the exploration of students' conceptual frameworks on their own terms and not in terms of their congruence with some predetermined standard (Driver & Easley, 1978). Additionally, a portion of my research was an investigation of the effects of context (social and cultural) on the development of students' knowledge. Clearly some form of interpretive research, focusing on complexity and context, was required for this investigation. The holistic approach afforded by qualitative methods offered a more probable opportunity of achieving an understanding of conceptual frameworks of evolution than the reductionism made necessary by quantitative methods.

Researcher

Because of my qualitative approach, researcher bias becomes an important factor in consideration of the study. My biases shaped many aspects of this study including the actual selection of the study content, the scope of the research questions and methods, and data analysis.

Biological Bias

My earlier graduate training was in the study of physiology at Auburn University. While this previous study may be considered far displaced from the consideration of evolution, Auburn's undergraduate and graduate courses in zoology were often oriented around the theoretical framework of evolution. Additionally, while an undergraduate and master's student, I was required to take separate courses in this area. These courses and my major professor shaped the selection of
my master's thesis, which was a physiological ecology problem, one that investigated the evolutionary and ecological significance of various physiological adaptations.

Given this earlier training and my subsequent teaching experience on the post secondary level, it is not surprising that I selected to study students' conceptual frameworks in evolution. These experiences also shaped the manner in which I approached this problem. While I had taught previously, I had not studied teaching. Therefore, the process of learning was the focus for my study and teaching was included only as it affected learning.

Most notably, this earlier training also shaped the manner in which I approached the topic of evolution. At the outset of the study, I considered the conceptual framework of evolution to primarily include evolutionary mechanisms. I consider the mechanisms of evolution to include the biological processes of natural selection, genetic drift, non-random mating, and other similar theoretical constructs. My training as a biologist ensured this approach. Secondary to the mechanisms, I considered the products of evolutionary processes to also be included in this framework. These products include biological adaptations, speciation patterns, and fossil records. My bias is shared by the Biological Science Curriculum Study, as shown in their definition of the knowledge required for biological literacy. In their list of "essential biological knowledge," BSCS (1992, p. 3) lists evolution, including genetic variation, natural selection, and patterns of evolution as the components of evolutionary knowledge required to become biological literate.

I entered my study using this scientific, mechanistic approach to the theory of evolution. However, my definitions for this theoretical construct expanded dramatically during the course of the study. The concept map interviews introduced me to the varied connections that are possible when the theory of evolution is approached with other than a scientific orientation. The student participants illustrated how their conceptions of
evolution interacted with other conceptions of human evolution, evidence for evolution, and the historical development of the theory.

Educational Bias

When my research questions and research methods are compared, a tension becomes obvious. While I proposed to use grounded theory to develop my findings, I also proposed to investigate the boundaries of the conceptual change theory (Posner et al., 1982). How can one use grounded theory when a theoretical commitment has already been established? My position within this debate is informed by Kuhn (1970) and Toulmin (1972). These philosophers of science have described the actions of a researcher's bias on the theories she selects. Even without the articulated bias of the conceptual change theory, I would approach the issue of learning from some theoretical framework. After all, theories allow us to make sense of the world. It is my position that it is far more illuminating to approach a study with firmly articulated biases; thus the actions of these biases can then be understood by the researcher as well as the reader. Additionally, I have not accepted and applied the conceptual change theory (Posner et al., 1982) uncritically. Instead, one of my research questions is to investigate the use and limits of this theory. While the tension between grounded theory and my theoretical background remains, my study represents a negotiation between these two extremes.

The Setting

My study took place in the University Laboratory School during the 1992-1993 school year. While the school is described in much more detail in Chapter 4, aspects of my selection require further discussion. The selection of this school as a site for the study has drawbacks. One could argue that I investigated conceptual change in a very narrow segment of the population. The students attending this school cannot be considered to be representative of the population of the public schools in our area due to the requirement for both tuition and transportation. However, previous research indicates that conceptual change seldom occurs during instruction on evolution (Bishop
My selection of a research site was deliberate, based on the uniqueness of the instructor, the students, and the curriculum of the class. This class was selected because it provided the best opportunity to document conceptual change.

Participants

Many different terms have been used to designate the persons involved in research. The choice of terms is important in that it signifies the researcher's intent in the study and her relationship with the persons involved. Interviewee implies a passive role for the participants. Subject has been selected by many researchers to avoid this connotation (Patai, 1987); however, subject implies a structured hierarchy in the researcher-researched relationship. The anthropological informant has many commonplace negative connotations. Therefore I have chosen participant to reflect the active position the teacher and students will have as they simultaneously participate in and shape the research. Seidman (1991) suggests that this term signifies an active involvement which occurs in extended interviewing and a sense of equity in the researcher-participant relationship.

Previous research into students' conceptual frameworks of evolution in which I have been involved was carried out with a group of college nonbiology majors. This choice was made because of my attempt to replicate the earlier work of Bishop and Anderson (1990). However, use of this group for this research is problematic. On a practical level, it would be difficult to work with a select group of college students throughout the semester as the attrition rate in these classes is considerable. More importantly, my previous research describes a student population whose conceptual frameworks of evolution have remained relatively unchanged during instruction, similar to the results of Bishop and Anderson (1990). Therefore, I could not be assured of identification of conceptual change working with this group. For this study, the focus of my research was a group of high school students, their parents, and their teacher.
The Teacher

My research was conducted in Ms. Hurston's Biology II class. The decision to work with this group is based upon the characteristics of its teacher: (a) she has been involved in past biology education research (Cummins et al., in press); (b) she is a national award winning teacher who is active in the National Association of Biology Teachers as well as the Louisiana Biology Educators Association; (c) she uses evolution as the unifying theme of her biology classes and realizes the implications and benefits of such an approach (Dobzhansky, 1973); and (d) she attended a workshop at Louisiana State University during June, 1992 which dealt with the teaching of evolution.

In this Biology II course, evolution was taught both as a distinct unit and integrated throughout the course. (See Chapter 5 for a description of the course curriculum.) This is not an advanced placement biology class, but is considered by the teacher to be a capstone class which integrates the knowledge from many of the sciences as suggested by the National Research Council (1990). The students in this class typically were eleventh and twelfth graders who selected this class as an elective. The work of Cummins et al. (in press) reports that past students in Hurston's classes were capable of using evolution as an explanation of ambiguous biological evidence. Based on the results of this past study and the characteristics of this teacher, I felt it was likely that I would be able to document conceptual change within selected students in her classroom.

The Students

The selection of interview participants always introduces the element of self-selection as these individuals must be willing to participate in the study (Bogdan & Biklen, 1992). The selection of individuals was based on principles of purposeful sampling in which maximum variation was sought (Patton, 1989). During the first month of observations, the instructor and I were involved in assessing the maximum range of individuals who constituted the class. However, we were purposefully
sampling for five students we felt would undergo conceptual change. This sampling technique served to limit my findings and this limitation will be further discussed in Chapter 6 and 7. Based on Hurston's and my assessment, I invited nine selected students to participate in the more in-depth aspects of the study. The assessment of the maximum range of students included factors such as gender, family background, educational background, religious beliefs, and familiarity with biology. While much of this information was known by Hurston, I also administered a science relationship questionnaire during the first week of my observations in order to elicit additional information needed for this decision. (See Appendix A.)

While nine students were selected to discuss their possible involvement in the study, only five had schedules which allowed their participation. Of these original five, three were girls and two were boys. The initial interview sessions were conducted very informally and held at any time the students found to be convenient. Later interviews were conducted at an established time during the school week. Unfortunately, after interviews had proceeded for over a month and a half, one of the male participants withdrew from the study. His stated reason for withdrawal was due to the inconvenience of the interview schedule. However, my own assessment was that he had begun to find the interviews tiresome. Another participant was not selected to take this position because of the time already elapsed. Therefore, I will report the data for four interview participants.¹

¹ While the fifth interview participant (Joe) contributed a great deal of data during our working relationship, it is my judgment that little of this data was useful in answering my initial research questions regarding conceptual change. Our interviews seldom touched on my research topics and instead remained steadfastly focused on the social aspects of student life at U High. Use of Joe's data, while illuminating in some regards, would have significantly altered the scope of my study and I chose to omit this information.
Other Participants

As a means of attaining a more defined understanding of the students' lives as the context for their conceptual frameworks, I interviewed the parents of the four students participating in the in-depth interviews. Information provided by the parents during our discussion conducted in March of 1993 provided valuable insight into how the students' conceptions, personalities, and their attitudes toward science have been affected by their families. The high school principal and high school counselor also participated in one open-ended interviews. These hour-long interviews were informal, and were conducted at a time and place at the participants' convenience.

Gaining Access

My first approach to gaining access into the classroom was through the instructor. We were previously acquainted through graduate classes and joint involvement in research. We had meetings in the spring before the beginning of the school year in which I expressed my interests, and we discussed tentative plans for the research. After gaining her consent, I approached the principal of the laboratory school in the summer before the research to gain administrative approval. This approval required my completion of a research request form and submission of my research proposal, each returned to the principal of the school.

Sources of Data

Patton (1989) argues that having multiple sources of data is one of the intrinsic characteristics of qualitative research. White and Gunstone (1992) discuss the limited understanding resulting from only one means of probing into students' conceptual frameworks. Wandersee et al. (in press) and Brumby (1984) explain that much of the previous work done in the area of students' conceptions has relied solely on paper and pencil tests which may produce a very slanted picture of the students' understanding of science topics. To counter the problems of previous research in this area and to provide adequate means of triangulating the data, I employed multiple sources of data for each of
the four participants. While interviews were the predominant method of data collection, these were augmented and shaped by participant observation within the classroom and collection of artifacts.

Classroom Observations

A portion of my study included observations of daily class activities of the entire group throughout the year. My position in the classes and in the school was a participant-observer. As discussed by Bogdan and Biklen (1992), this role is actually a fluid continuum. This was also true in my study as my role as a participant observer represented a constant balance between participation and observation. In some instances I acted as a teacher. On two occasions when Ms. Hurston had to be away from the classroom I was responsible for the class. I also presented two lessons, one on concept mapping and another on speciation patterns. During laboratories students would approach me for help when Hurston was otherwise engaged. I escorted students on field trips and acted as an adult chaperon. I also acted as a student participant as the students whispered humorous comments to me during or after class and during the laboratories when I participated alongside students in their small groups.

The other side of the continuum was the complete observer. This typified my early observations in the classroom as I watched quietly from the back of the classroom while taking constant notes. At all times I strove to be nonjudgmental and nonauthoritarian except in cases when the class was left expressly within my control. However, it must be noted that even my most detached observations affected the participants’ behaviors. Often I knew students were making comments deliberately so that I would hear them. Throughout the study, I was a source of interest to the students as they asked me questions, looked over my notes for that week, and watched to see what I would choose to write about.

I observed the class for the entire year for a variety of reasons. The first is that I felt I needed lengthy observations to allow the establishment of a comfortable rapport
with the students needed for successful in-depth interviewing. Observations limited to
only the teaching of evolution could have distanced me from the students to such a
degree that they could not become comfortable during our interviews. By mid-year, I
felt I had established a comfortable relationship with almost every member of the class.
Students often made efforts to talk to me before, during, and after classes. These
students would bring to my attention things they thought I would be interested in, both
on a personal and research level.

In addition to the rapport established, understandings gained from the participant
observations were needed to answer research questions such as a description of the
activities which catalyze conceptual change and the degree of compartmentalization of
students' biological knowledge. My observations in the classroom also shaped the
selection of the students to participate in the interview, the content of the interviews, and
selection of artifacts for analysis.

Interviews

Interviewing was the most important means of data collection used in my study.
West and Pines (1985) describe interviews as one of the best approaches to use in
discovering students' conceptions. Seventeen interviews were conducted with each of
the four student participants. These numerous interviews were essential to the research
in that they allowed me the opportunity to describe and then verify and clarify my
descriptions of the students' understandings (Hutchinson, 1990).

The interviews conducted ranged from very structured to very open-ended, a
selection dictated by the specific content in question. Typically, interviews begin in a
very open-ended manner, with later sessions becoming more structured as the researcher
develops more specific questions from the data (Seidman, 1991). However, I conducted
interviews reminded of the suggestion of Lythcott and Duschl (1990) that the key to all
successful interviews is providing the participant as much freedom of expression as
possible.
The open-ended interviews allowed me the opportunity to understand how students negotiate meaning in the area of evolution. This is a very contextual, specific understanding. The structured interviews allowed the opportunity to develop descriptions of students' conceptual frameworks with great mode validity; that is, the descriptions generated are a reflection of many modes of investigation (White & Gunstone, 1992). Additionally, these structured interviews provided an opportunity to gather comparable data from all the students to allow comparison across individuals. Thus, both types of interviews were integral to the goals of my research. (See Figure 2 for a time line of the student participant interviews.)

The instructor, the four students, the parents of these four students, the high school principal, and high school counselor were interviewed. Interviews with the individual students occurred about once a week, during a pre-established period within the school day. Their lengths varied from as short as 20 minutes to as long as 45 minutes per session. The interviews with the teacher were conducted opportunistically throughout the course of the study. The parents were interviewed once toward the end of the study. The principal and counselor were interviewed one time during the initial months of research. Insight from informal discussions with other students in the class, the student teacher, and other science education teachers were also used to provide another dimension to the description of the teacher observed in this study.

Open-Ended Interviews

For the open-ended interviews, I used an interview guide for reference and prompting, although I never strictly adhered to these guides (See Appendix B for specific questions.) As suggested by Seidman (1991) the initial questions in the open-ended interviews were very broad, and later questions narrowed as I attempted to describe and verify the participants' conceptions. The research areas explored during open-ended interviews ranged from areas as diverse as students' personal characteristics, attitudes toward religion, and ideas of schooling, to the more science oriented such as conceptions
of mutations, species, and patterns of evolution and students' attitudes toward pseudosciences. (See Table 1 for a list of open-ended interview topics and Appendix B-1 for a sample of interview questions.)

Year Beginning (August 14, 1992)

<table>
<thead>
<tr>
<th>Artifact Number</th>
<th>Interview Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artifact 1</td>
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</tr>
<tr>
<td></td>
<td>3 4</td>
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<tr>
<td></td>
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<td>11 12</td>
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<td>13</td>
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<td>Artifact 6</td>
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<td></td>
<td>17</td>
</tr>
</tbody>
</table>

Figure 2
Timeline of the student interviews and the interviews used for the three conceptual frameworks
Table 1
Subject of open ended interview sessions with student interview participants

<table>
<thead>
<tr>
<th>Interview Symbol</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1</td>
<td>School: Personal Information: Teaching</td>
</tr>
<tr>
<td>I-2</td>
<td>Evolution: Mutation: Science/Biology</td>
</tr>
<tr>
<td>I-3</td>
<td>Animal Behavior: Pseudoscience</td>
</tr>
<tr>
<td>I-4</td>
<td>World View</td>
</tr>
<tr>
<td>I-5</td>
<td>Scientific Theories</td>
</tr>
<tr>
<td>I-6</td>
<td>Human Taxonomy</td>
</tr>
<tr>
<td>I-7</td>
<td>Holidays: Religion: Family Habits</td>
</tr>
<tr>
<td>I-8</td>
<td>Biology: Evolution as a Biological Theory: Evidence for Evolution: Application for Evolution</td>
</tr>
<tr>
<td>I-9</td>
<td>Age of Earth: Successful Species: Comparison of Species: Predictability of Evolution</td>
</tr>
<tr>
<td>I-10</td>
<td>Natural Selection</td>
</tr>
<tr>
<td>I-11</td>
<td>Boundaries of Science, Religion, Philosophy</td>
</tr>
<tr>
<td>I-12</td>
<td>Biblical Interpretation</td>
</tr>
<tr>
<td>I-13</td>
<td>Species: Understanding of Evolution</td>
</tr>
<tr>
<td>I-14</td>
<td>Adaptation: Mutation</td>
</tr>
<tr>
<td>I-15</td>
<td>Personal Characteristics: View of Research Process</td>
</tr>
<tr>
<td>I-16</td>
<td>Competition: Limits of Evolutionary Theory: Differential Reproduction</td>
</tr>
<tr>
<td>I-17</td>
<td>Biology Class</td>
</tr>
</tbody>
</table>
The open-ended interviews with the parents of the four student participants were conducted to better understand the family context of the students. Questions asked of the parents were selected to elicit their attitudes toward school and science. These interviews were conducted towards the end of the study, after I had a well defined description of the participant. Then, the parental interviews were used to verify and clarify my conceptions. (See Appendix B-2 for a sample of the parental interview questions.)

An open-ended interview with the school principal and counselor were conducted to better understand the school's impact on the activities of the classroom and the types of knowledge valued by the administration. The issues included (a) administration standards, (b) the school's student body, (c) college trajectory of students, (d) parental involvement, (e) curricular issues, and (f) her/his views toward science education. (See Appendix B-3 for a sample of the principal and counselor interview questions.)

Structured Interviews

Each of the four students participating in the interviews was involved in structured interviews similar to the clinical interviews discussed by Lythcott and Duschl (1990). Structured around the student's explanation or production of a graphic, these interviews were planned to enhance the description of the student's conceptual framework of evolution and to document and describe instances of conceptual change. Because understanding is too complex to be adequately described using any one technique, a variety of techniques were used to probe students' understandings (White & Gunstone, 1992). A list of the types of structured interviews and the subject of those interviews can be found in Table 2.

Concept mapping

The most valuable set of structured interviews involved the use of concept maps. Concept maps were used to allow the student to express her/his understanding of evolution before, during, and after instruction. Concept mapping was particularly useful for this study in that its use went beyond the expression of information and allowed the
students to express their knowledge, which Wandersee (1989, p. 6) describes as an "organized body of meaningful concepts which is a product of inquiry."

Table 2
Subjects and types of structured interview sessions with student interview participants

<table>
<thead>
<tr>
<th>Interview Type</th>
<th>Subject</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Map</td>
<td>Understanding of Evolution</td>
<td>CM-1</td>
</tr>
<tr>
<td>Concept Map</td>
<td>Process of Evolution</td>
<td>CM-2</td>
</tr>
<tr>
<td>Concept Map</td>
<td>Process of Evolution-Seed Terms</td>
<td>CM-3</td>
</tr>
<tr>
<td>Interviews about Instances</td>
<td>Biological Natural History-Recent</td>
<td>IAI-1</td>
</tr>
<tr>
<td>Interview about Instances</td>
<td>Evolutionary Patterns: Speciation</td>
<td>IAI-2</td>
</tr>
<tr>
<td>Interview About Instances</td>
<td>Patterns of Evolutionary Changes</td>
<td>IAI-3</td>
</tr>
<tr>
<td>Prediction Interview</td>
<td>Mutation</td>
<td>PI-1</td>
</tr>
<tr>
<td>Prediction Interview</td>
<td>Genetics</td>
<td>PI-2</td>
</tr>
<tr>
<td>Sorting Task</td>
<td>Process of Evolution</td>
<td>ST</td>
</tr>
<tr>
<td>Word Sort</td>
<td>Description of Evolution</td>
<td>WS</td>
</tr>
<tr>
<td>Bishop and Anderson Test (1985)</td>
<td>Natural History</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Process of Evolution</td>
<td>T</td>
</tr>
</tbody>
</table>

Concept maps are the schematic representation of concepts situated in a framework of propositions (Novak & Gowin, 1984). The graphic representation of a concept map is based on a hierarchy of related concepts linked by propositions which articulate the concepts' relationships. While this tool is a powerful way for students to negotiate meaning, it also can be used to externalize the student's thinking. Novak (1990) explains that concept mapping is a very sensitive means of measuring changes in a student's knowledge structure. The combination of clinical interviews with concept maps is a versatile and useful investigative technique into conceptual change (Wallace & Mintzes, 1990). My selection of concept maps as an assessment tool was based on this strength.
The maps do not represent knowledge linearly which would limit expression to the logical structure of the knowledge. Instead, concept maps are organized hierarchically and ideally fan out in a web-like fashion. Thus, concept mapping reflects the psychological structure of the knowledge (Wandersee, 1990). It is this characteristic that provides its power of expression.

Concept mapping is effective in displaying the student's understanding of the relation between the concepts of a wider discipline by focusing on structure and linkages between concepts. This technique is also valuable in that it avoids much of the confusing effects of students' differing vocabulary and writing styles (Novak & Gowin, 1984). The students in the biology class were involved in concept mapping early in the year when a science education researcher, Jim Wandersee, presented a lesson on concept mapping. Two additional days were used for students to practice this technique under my direction. Although this teaching tool was not heavily used by the teacher, Ms. Hurston, each of my four interview participants indicated that they had used this study technique in many of their previous science classes.

In my original proposal, I had suggested that the first mapping session would be used to allow students to use any terms they felt were appropriate in mapping their understanding of evolution. In subsequent mapping sessions, I proposed the use of five seed terms dealing with the concept of evolution with the students adding any additional concepts to their map (Trowbridge & Wandersee, in press). The five seed concepts to be included in the later interviews were (a) evolution, (b) natural selection, (c) population, (d) change, and (e) mutation. Seed terms were used to insure a common basis for the maps which were useful in comparing understandings over the course of the year and comparing different students' understandings. Asking students to add their own terms also served to add to concept mapping's inherent ability to allow for variation in the expression of students' knowledge.
Thus, originally I proposed to have three maps from each student over the course of the study. However, as is the case with qualitative work, my participants changed my original plans. In my first concept mapping interview, I asked the participants to map their "understanding of evolution." (This type of concept map was given the research symbol CM-1.) After looking at these maps, I noticed that one of my participants mapped the historical development of the theory and its anthropological considerations. This map was far different from those of the other three participants and also radically different from the mechanistically oriented map I would draw. Based on this result, the next week I asked the students to map "your understanding for how evolution works." (This type of concept map was given the research symbol CM-2.) Additionally during mid-year, I asked the students to construct a third type of map given the use of the five seed terms. (This type of map was given the research symbol CM-3.) After completing the map, the student was asked to explain her/his maps.

Students were asked to construct CM-1 at the beginning and close of the study. They were asked to construct CM-2 at three times in the study - at the beginning, the midpoint, and end. Finally, the seed term map, CM-3, was used only once during the midpoint of the study. Thus, I used a total of six maps for each student. (See Table 3 for a summary of the interview schedule and the research tools used.) (See Appendix C-1 for a sample of the interview questions used in the structured interviews.)

Interviews about instances

In the second type of structured interview, the students were presented a series of pictures and asked questions. Such a technique is referred to by White and Gunstone (1992) as an interview about instances. This technique was useful in providing a description of the student's ability to recognize or use a concept and has also been helpful in detecting alternative conceptions of students (Franklin, 1992; Osborne & Freyberg, 1985).
<table>
<thead>
<tr>
<th>Interview Session</th>
<th>Date</th>
<th>Type of Data Collection Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/6/93</td>
<td>I-1</td>
</tr>
<tr>
<td>2</td>
<td>10/13/93</td>
<td>I-2: T</td>
</tr>
<tr>
<td>3</td>
<td>10/20/93</td>
<td>I-3: CM-1</td>
</tr>
<tr>
<td>4</td>
<td>10/27/93</td>
<td>I-4: CM-2: ST</td>
</tr>
<tr>
<td>5</td>
<td>11/3/93</td>
<td>I-5: IAI-1</td>
</tr>
<tr>
<td>6</td>
<td>11/10/93</td>
<td>I-6: IAI-1</td>
</tr>
<tr>
<td>7</td>
<td>11/17/93</td>
<td>I-7: PI-2</td>
</tr>
<tr>
<td>8</td>
<td>12/2/93</td>
<td>I-8</td>
</tr>
<tr>
<td>9</td>
<td>1/12/93</td>
<td>I-9: IAI-2</td>
</tr>
<tr>
<td>10</td>
<td>1/19/93</td>
<td>I-10: IAI-3: D</td>
</tr>
<tr>
<td>11</td>
<td>5/6/04</td>
<td>I-11:</td>
</tr>
<tr>
<td>12</td>
<td>2/2/93</td>
<td>I-12: CM-2: CM-3: ST:</td>
</tr>
<tr>
<td>13</td>
<td>2/9/93</td>
<td>I-13: WS: PI-1</td>
</tr>
<tr>
<td>14</td>
<td>3/16/93</td>
<td>I-14: IAI-1: PI-1:</td>
</tr>
<tr>
<td>15</td>
<td>4/6/93</td>
<td>I-15</td>
</tr>
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<td>16</td>
<td>4/22/93</td>
<td>I-16: CM-1: ST: PI-1:</td>
</tr>
<tr>
<td>17</td>
<td>4/29/93</td>
<td>I-17: T: CM-2</td>
</tr>
</tbody>
</table>

Specific areas investigated with this technique included (a) the use of typological species concepts, (b) the meanings students assign biological adaptation, (c) their understandings of phylogeny, (d) their use of anthropomorphic and teleological conceptions of evolution, (e) their species concept, and (f) their conceptions of the patterns of evolutionary change. The situations presented to the students in this aspect of the study were, in part, suggested by Clough and Wood-Robinson (1985b) in their study.
of children's understandings of biological adaptations. Students' application of
 evolution to explain some of these phenomena was often used to measure the
 participants' comfort with this theory. (See Appendix C-2 for a description of the
 graphics and a sample of the interview protocol.)

Prediction interviews

A third type of structured interview, prediction interviews, assessed students'
 abilities to predict the outcome of an inheritance event (PI-2) (similar to the work of
 Kargbo et al., 1980) and a mutation event (PI-1). White and Gunstone (1992) explain
 that this technique is more direct than other structured interviews in revealing
 understanding, because it distinguishes between rote and meaningful learning while
 assessing the student's ability to apply the concept. A similar exercise was used by
 Franklin (1992) in his investigation of students' understanding of electricity. However,
 he administered this exercise in a written format, with the students selecting the most
 appropriate answer and justification for that answer.

In this interview, the student was presented with a graphic and an explanation of
 a situation. The student was then asked to form a prediction of the outcome and provide
 a written and then verbal explanation of the prediction. Much of the value of this
 technique was found in the student's explanations of their prediction. The student was
 shown a graphic detailing the outcome of the event and asked to describe what she/he
 saw and to verbally reconcile this outcome with the prediction. This technique had the
 added advantage of making obvious the effects of theories and beliefs on the student's
 observations of the graphics. (See Appendix C-3 for the graphics used in the prediction
 interviews and a sample of the interview questions.)

Sorting interview

In this fourth form of structured interview, the student was shown a series of
 graphics which displayed the various occurrences in an evolutionary event driven by
 natural selection. The student was then asked to sort these cards in any order that
expressed her/his understanding of the evolutionary process by using the think aloud technique (Smith, 1983). This interview was repeated at the beginning, middle, and end of the school year in an attempt to assess conceptual frameworks and to describe instances of change. This technique had the advantage of allowing me to investigate instances of anthropomorphic and teleological explanations formed by the participant as well as investigating the factors the student viewed as necessary for evolution driven by natural selection. (See Appendix C-4 for the graphics used in the sorting task as well as a sample of the interview protocol.)

Word sort interview

This technique is a derivation of a method used by Hauslein et al. (1992). For this structured interview, the participants were presented with a series of eight terms. These included: design, drastic, success, need, random, chance, subtle, and order. The students were then asked to sort the terms into two groups: terms which could be used to describe evolution and terms which could not be used to describe evolution. As with all the structured interviews, the participants were encouraged to think aloud as they worked. In a derivation from Hauslein et al. (1992), the transcripts from the think aloud, and not the actual sorted groups themselves, formed the data for this interview. As described in Hauslein et al. (1992), these transcripts provided a means to determine the basis from which the participant created categories. These terms were selected to measure the participant's understanding of both the mechanism of evolutionary changes and the patterns of those changes.

Drawing interview

As White and Gunstone (1992) have argued, there is a great dependence on words for most instruments designed to study students' conceptions. To counter this over reliance, White and Gunstone (1992) suggest the use of student produced drawings. This technique has the advantage of allowing students to express their knowledge in a very unlimited manner; thus, the students reveal characteristics of their
understanding that may be masked through more verbal means. Due to this freedom of responses, drawings allow the researcher another mode through which to study students' conceptions.

I chose the technique of drawing to measure students' conceptions of the history of life on earth. For this form of structured interview, I asked the participants to "draw a time line of the history of life on earth." Not only was this interview used to measure the participant's knowledge of the long-term natural history, but this interview was intended also to illustrate the taxa with which the participant was familiar. After the drawing was complete, each participant was asked to explain her/his time line. (See Appendix C-6 for sample interview questions.)

**Written Examinations**

While the descriptions of changing conceptual frameworks of evolution were limited to the four students participating in the interview, the entire class was asked to participate in an examination of evolution by natural selection at the beginning and end of the study. The exam was written by Bishop and Anderson (1985) and formed the basis of my original study. This exam was selected because of the data base created through its use in other studies in this area (Bishop & Anderson, 1990; Demastes, Settlage, & Good, in press; Jensen & Finely, 1993; Settlage, in press).

The exam consists of multiple choice and essay questions regarding the process of evolution by natural selection. (See Appendix C-7 for the exam and a sample of the interview questions.) The purpose of this examination was to assess the degree of conceptual change occurring within the general class population. Additionally, the four interview participants were asked to verbally discuss their explanations in an interview. This discussion helped in achieving an understanding of students' teleological, anthropomorphic, and typological explanations of biological phenomena as compared to their written explanations. Additionally, the students' verbal explanations of their written
answers may be informative in interpreting other research which uses this same instrument.

Artifacts

I used several artifacts from the classroom as additional data sources for the description of conceptual frameworks. These artifacts included:

1. Students' journal entries discussing the evolution of humans,
2. Students' journal entries discussing the evolution of the human appendix in comparison to the pig cecum,
3. Students' answers to an exam question on extinction theories,
4. Students' homework on the topic of physical patterns in nature,
5. Students' journal entries on natural patterns,
6. Students' journal entries on anthropology, and
7. Students' final exam answer describing the theoretical framework of biology.

These were materials assigned by the teacher for the purpose of teaching; however, we both felt that these materials were also valuable research data.

Other artifacts were studied to better describe the school setting and curriculum. These artifacts included school notices, brochures, flyers, graduation announcements and ceremony programs, and the school yearbook.

Data Collection Techniques

Each source of data previously discussed had to be transformed into actual data for analysis. For several sources, such as the written examinations and classroom artifacts, this conversion simply required making a photocopy. Other sources of data required a more laborious conversion before formal analysis.

Transcripts

Transcripts from audio- and video-taped interviews formed the main body of data for my research. For the open-ended interviews which did not require graphics for interpretation, the interviews were audio-taped. For the structured interviews, the
participants were both audio-taped and video-taped. While the audiotapes were used for the bulk of the transcriptions, the videotapes provided additional information detailing the students' movements as they reacted to the material.

Transcripts were typed on a word processing program in the same manner as the field notes, with the verbatim transcripts in the left hand column to leave space for analytical comments made during analysis on the right hand side.

Field Notes

Descriptions of each observation and interview were entered in my field notes. These notes contained physical descriptions of the research participants and their behavior, my behavior, the activity in question (through verbal and graphic means), along with a description of the verbal and nonverbal communication occurring during the activity. Bogdan and Biklen (1992) refer to these notes as "the written account of what the researcher hears, sees, experiences, and thinks in the course of collecting and reflecting on the data in a qualitative study" (p. 107).

The actual description in the field notes were made in one column on the left hand side of the page. The right hand side of the page was reserved for analytical comments made at the time of observation, or later as data were continually analyzed. This structure served as an attempt to isolate description from obvious interpretation, although I acknowledge that the observations themselves were often influenced by my on-going interpretations. While notes were made during the participant observations and the interviews, the field notes were elaborated and entered into a word-processing program. The field notes served to reconstruct events and to record as much detail as possible.

Field notes were particularly important for the study of the classroom as they were the major source of data for this aspect of the research. The field notes were also kept for the interviews which served as another source of data in addition to the transcripts of the audio and video recordings.
Field Journal

The field journal involved a narrative description of the activities of the research day. This narrative was more personal than the field notebook. Here the emphasis was on my biases, feelings, ideas, and attitudes. Initial analyses were often recorded, as were descriptions of events that went very well or very poorly. A picture of my subjectivity was formed from this narrative. This picture allowed me to reflect on the effect of my subjectivity on the data collection and analysis and thus allowed a clearer understanding. Additionally, the journal provided an informal means of reflection on the method of data collection and analysis, my attitude toward the research and participants, and any ethical problems that arise (Bogdan & Biklen, 1992). Because the data collection was shaped by the on-going analysis, the insight gained from my field journal was fundamentally important. The ongoing analytical comments made in these journals were invaluable as I attempted to reconstruct my analysis during the latter stages of the study.

Analysis

The analysis of data was carried out in a manner described by Glaser and Strauss (1967) in their discussion of grounded theory. Development of a grounded theory includes an interpretive analysis accomplished by defining or isolating theories and concepts directly from the detailed data centering on the participants. By using the grounded theory approach to qualitative study, the intent is not to prove predetermined theories, but to generate theories from the data and to provide supporting evidence. The researcher attempts to analyze the data with a minimum of previous assumptions and instead looks for trends and patterns to emerge from the data. Hutchinson (1990) provides an excellent explanation of the strengths of analysis based on grounded theory:

Grounded theory offers a systematic method by which to study the richness and diversity of human experience and to generate relevant, plausible theory which can be used to understand the contextual reality of the social behavior. (p. 127)
Because the researcher attempts to make inferences solely on the basis of trends seen in the data, elaborate theories constructed by the researcher beforehand may well interfere with the discovery process. To eliminate this problem, many researchers advise a minimum of literature review by the researcher until the actual research process is underway (Taylor & Bogdan, 1984). However, as I have argued earlier, each researcher carries a bias into a project and the data collection and analysis are influenced by those biases. The researcher cannot avoid relying on common sense knowledge and prior conceptions. With this in mind, Hammersley and Atkinson (1989) advise that biases be explored and well documented so their effects can be understood and the data analyzed in the best manner possible. Bogdan and Biklen (1992) suggest that "Good researchers are aware of their theoretical base and use it to help collect and analyze data" (p. 33). I agree more with the latter opinion, and, for that reason, I included a literature review and a description of my initial areas of interest in the research proposal.

A fundamental requirement of the grounded theory approach is making inferences from observations. Instead of attempting to explain observations from a preestablished governing law, an attempt is made to link observations into a pattern, to provide explanations for the pattern, and then to construct an intelligible frame or theory. Because of the nature of inferences, the theories constructed need to remain closely tied to the subject and generalizations for entire groups may not be possible (Geertz, 1973).

The benefits of basing analysis on grounded theory as described by Richer (1975) and Glaser and Strauss (1967) is due to its inductive basis. Grounded theory has the potential of moving beyond current theories or paradigms by producing theories which may provide more useful insight into the situation studied (Stern, Allen, & Moxley, 1982). Additionally, such analysis is ideally suited to form initial description and explanations of complicated situations (Hutchinson, 1990). These characteristics make grounded theory well suited for the case studies needed in science education (Stake & Easley, 1978).
My analysis began through the formulation of substantive codes that described pieces of data. These substantive codes were often the actual terms the participants used or were terms I felt were descriptive of the pattern. Because of this latter category, how I make sense of the world influenced my selection of items assigned to a particular code (Bogdan & Biklen, 1992). All data were assigned a code in order to break the data into small, understandable pieces, such as students' attention seeking behaviors. Afterwards, I read the data many times and assigned the substantive codes to larger categorical codes, such as classroom power relations. In turn, the data were read to assign substantive and categorical codes into theoretical constructs, such as the extreme importance the students placed on academic knowledge. These constructs were formed from the combination of data, knowledge gained from the literature, and my knowledge from the outside world. The process of coding began at the outset of data collection.

During coding, memos were attached to various codes offering my tentative theoretical ideas concerning the particular code. Because coding occurred throughout data collection, it shaped my opinions and so shaped the data collection. This reflexivity allowed me to search for data that provided examples of proposed codes and to check my emerging understandings with the research participants. The process of specified data collection is referred to as theoretical sampling. These very directed questions insured construct validity of the inferences made from the data. Additionally, this directed process of data collection insured very dense data for each theoretical construct.

Toward the end of the study, I began to sort all the data that supported or explained the most prominent theoretical constructs. Glaser and Strauss (1967) refer to these prominent theoretical constructs as basic social psychological process, and Glaser (1978) refers to them as the main theme in the data. This sorting began the formal process of theory generation as I attempted to apply meaning provided by these prominent theoretical constructs to the larger body of data. The process defined the data which do and do not apply, thus establishing the limits of the emerging theory.
Another essential part of the analysis process involved participant verification of my emerging theories. As I began identification of themes, I discussed these theoretical constructs with Hurston and each of the interview participants. Their ideas were used to verify or modify my original analysis. In a small number of instances, my views could not be aligned with that of the participants. In these cases, both the participants' and my own analysis appears and the reasons for the possible discrepancies are discussed.

Analysis based on the grounded theory approach is concurrent with data collection. This allows additional data to be gathered to answer research questions as they arise and allows the researcher to establish the construct validity of her/his emerging theories. However, data analysis continued months after the data collection ended and far into the time of formal writing.

I analyzed the data from each student separately. However, at the outset of the final reading, I summed each area mentioned by the students about the theoretical framework for evolution. These conceptual areas were placed in a template describing each participant's conceptual framework for evolution. In order to document conceptual change, the participants' conceptions for each aspect of this framework were described at three intervals during the research process. The interviews involved for each of these three intervals can be found in Figure 2.

I analyzed the data from each student separately, and then compared my understandings of the individual students in a componential analysis. This procedure allowed me to develop an understanding of each student on an individual basis. Afterwards, the comparison of individuals allowed identification of patterns that were common throughout the individuals involved in the study. Thus, componential analysis allowed the initial steps from contextual understanding toward generalization of insight constructed from the study. We must recognize that this is only a tentative step toward generalizability that must be further investigated through other research.
Time Frame of Study

As shown in Figure 2 and Table 3, the data collection extended throughout the 1992-93 school year. This duration was necessary for me both to establish a close, working relationship with the participants and to provide an opportunity for a longitudinal study of conception change. Arzi (1988) has critiqued current research in science education and explained that short term studies do not relate a full understanding. She calls for more longitudinal studies which follow the same subjects over an extended time frame.

Ethical Issues

Stacey (1988) and Lather (1986) have illuminated the inherent difficulties in traditional relationships between the researcher and the participants. They argue this relationship as typically conceived is exploitative and serves to reproduce the power relations of the larger society. While this reproduction is problematic on moral grounds, the theoretical underpinnings of qualitative research also make this traditional relationship less than appropriate. Munro (1991) argues that the intersubjective process of meaning making demands that this relationship be collaborative and reciprocal.

In an effort to make this a collaborative relationship, the participants in this study shaped both the actual scope of the study and the methods I used. Additionally, I shared my analysis with each individual before dissemination of the study and invited their comments on the interpretations included in writing of the dissertation. Their comments, although minor, were incorporated into the analysis. In very few instances did their analyses firmly conflict with my own; although when this did happen, both views were reported. (See Chapter 4.)

Seidman (1991) explains that the in-depth interviewing process has the potential of being particularly damaging for the participants when the topic of inquiry is to be situated in the life of the participant. Such a process is likely to raise sensitive issues at the same time that it provides a large body of description. Such description may allow
identification of the participant, even though the identity of the participant is to be
disguised. This last concern is particularly important because the vulnerability of those
involved in the research cannot be discerned ahead of time. Because of these concerns, I
used informed consent forms for each of the participants to detail what their
responsibilities were in the research and to clarify their right to withdraw from the study
at any time. These forms were signed for the students by their parents or guardians.
Although University Laboratory School students have agreed to participate in all research
when they enrolled, I felt this additional step helped ensure the voluntary nature of the
students' participation.

In an effort to maintain confidentiality, I used pseudonyms for each participant in
the study and masked the name of the school itself. The pseudonyms were used in all
my notes, journals, and transcriptions so even an outside reader of the rough transcripts
would be unaware of the participants' identities. I was the only person involved in the
bulk of the transcriptions, although a professional transcriptionist was employed for a
small percentage of this work. Her participation was agreeable to the research
participants.

**Reflexivity**

In the ethics section I discussed the issue of reflexivity. Because of the nature of
qualitative research, the voice of the researcher cannot be separated from that of the
participants. This point has been well documented in the literature in discussions by
Munro (1991), Roman (1989), and Stacey (1988). But in turn, the notion of reflexivity
also implies that the voice and actions of the participants cannot be separated from the
role typically held by the researcher. This relationship is easily seen in the methods used
in this research. Ms. Hurston, the teacher, suggested and provided many of the research
instruments used in this study. She also played a large role in the selection of research
participants and in on-going data analysis. Hers were not the only efforts that changed
the focus and methods of my study. As has been described, the results of one concept
mapping session with a student participant demonstrated for me the narrowness of my understanding of a scientific conceptual framework for evolution. Thus, this student radically expanded my research scope.

As will be discussed in Chapter 6, this reflexivity is not limited to the participants' alteration of my methods and analysis. As will be seen, my efforts substantially changed the nature of the participants' learning, so that these students experienced more conceptual change than their classmates. Thus, my actions as a researcher changed the experiences of my participants. Given this relationship, it would be difficult to defend a description of this study as naturalistic, because, not only did I observe, I also modified.
PREFACE TO
THE RESULTS AND DISCUSSION CHAPTERS

The focus of this study is the conceptual change which occurred in four Biology II students in the topic of biological evolution. However, it is important to know how the learning of these four interview participants compares with that of their classmates. In addition, to better understand the conceptual change that is described, the learning of these students should be situated within the teaching practices of their Biology II course as well as the culture of the classroom in which this learning took place.

Toward these ends, the results and discussion are reported in three chapters. Chapter 4 is a description of the classroom culture. Chapter 5 is a description of the teacher and her teaching practices. This chapter also specifically addresses the means through which evolution was taught. Finally, Chapter 6 is the most important for the purposes of this study. Here, the conceptual change is described, both on a whole class basis and on an individual basis with the four interview participants.
CHAPTER 4
CLASSROOM CULTURE

No educational event exists in a vacuum. It is created and influenced by its larger cultural context. Even though the focus of my study was the process of learning of four particular students, much of their learning occurred in a classroom. And this classroom has a culture. Culture is not a language, a style of dress, or a unique social practice. Instead I understand culture to be the ever-changing context in which an individual makes sense (Geertz, 1973). To describe a culture is, in part, to describe how meaning is negotiated by the members of a group. Thus, culture can be explicit knowledge as well as tacit, nonverbal knowledge which is continually taught, learned, and modified by group members (Clifford, 1986). To understand culture is to understand the knowledge that a group values. Therefore, it is important to provide for the reader a description of the culture in which my study takes place.

My work focuses on the students of one biology class. The understandings I have gained center on the culture of this class as it is situated in the larger high school. I have attempted to represent the themes through which I came to understand the school. However, in an attempt to refine my understandings, I had the students of this class comment on a early draft of this chapter. My initial understandings have been altered by the students' perceptions, and their comments are interwoven with my own. Through this process of description, reflection, and refinement, I hope to achieve a richer description, one that reflects my views and those of the participants.

This chapter begins with a description of the school, both through physical and administrative lenses. Afterwards, the biology classroom and the class participants are described. These descriptions are designed to give the reader a basis from which to understand the themes that follow. Finally, the themes that I found to be important are discussed along with the students' reactions to my descriptions. I came to recognize three themes as important factors in the culture of this class. These are (a) Talking
discussed along with the students' reactions to my descriptions. I came to recognize three themes as important factors in the culture of this class. These are (a) Talking Academic, (b) A Small Town School in an Urban Setting, and (c) the Myth of Uniformity. These three themes are interwoven and, as will be seen, the action of one theme often mediates the actions of another. I propose no sharp distinctions that would be easily recognizable to a reader who visited my study site. But I hope through my descriptions to provide the reader with an understanding of the contexts in which my study took place.

The School

Physical Appearance

To any passerby, the University Laboratory School easily blends into the rest of the university campus. Situated beside the law school library and facing a row of fraternity houses, the laboratory school lies on the fringes of the university grounds. The school is constructed of familiar beige bricks used in many campus structures, several of them showing some green algal growth in the face of Louisiana's subtropical climate. There is a large yard surrounding the school, its grass uniform except where it is shaded by the large, lush oaks similar to those found throughout this part of the deep South.

A visitor can walk from the university campus and enter the side of the school by following a pathway in the grass trampled by innumerable College of Education students over the years. The handrails lining this side entrance were yellow at one time, but now metal peeks through, worn by the passage of many hands. For a portion of the school year, the glass side door leading to the high school wing was broken, and the cracked glass was held in place with gray duct tape. When I first entered the school in the fall semester, I was greeted with a familiar atmosphere of schools-a building kept a little too cold in the summer and a little too hot in the winter, floors typically free of
debris but always in need of a mop, lockers filled to overflowing at times with books, papers, notes, and tennis shoes.

But as I look closer, I notice that this school hallway differs in several ways from others I have walked. On any given day, backpacks line the walls with no one present to guard their contents. Many times I notice official looking notes addressed to specific students taped onto the lockers. Unattended students pour over exams in the hallways.

These differences fade as I watch the activity between class periods. Then, just like many high schools, the hallways are filled with talking, laughing, singing students. I can hear students making contact before the next period—the seniors making plans for lunch off campus, younger students darting in to buy an off limits candy bar from the vending machine. Often younger students chase one another, falling short of actually bolting through the hallways. Teachers, though not obvious in this short time of student freedom, can be seen lingering near their doors and occasionally looking out at the activity.

The majority of the higher grade levels classes are held within the same two story wing of the laboratory school. This allows maintenance of a distinction between the upper and lower grade levels. The students refer to the ninth through the twelfth grades as University High, or more casually, U High. This sense of a separate identity is reinforced by the small number of younger children seen in the high school's hallways, and the rule prohibiting the older students from using the younger hallways as a passage out of the building.

History and Administration

The University Laboratory School was first opened in 1915, under the name of the Demonstration High School. Its initial purpose was to provide teacher and college student education in high school teaching methods and to provide facilities for teaching practice. Throughout the intervening years, additional grade levels were added. The
Laboratory School is a department in the College of Education at the university. Funding for the school comes from both student tuition and state "minimum foundation funding" appropriated to the university. Thus, the laboratory school is a member of the university system and is not formally associated with the parish school system. This relationship is reflected by the Laboratory School's schedule, which corresponds to that of the university and not to that of local public schools. In its current form, the University Laboratory School has a maximum population of 760 students attending kindergarten through grade 12. Each grade level has a constant number of 70 students, composed of 35 males and 35 females. Approximately 10% of the student population of the school includes members of minority groups.

Typically, anywhere from 600 to 1000 applications are received for the estimated 85 to 100 openings. Most openings are for kindergarten and ninth grade. Once students have applied, they are placed into established demographic and educational categories. This information is then given to a central committee on the university's campus, and this committee makes the decision as to which students to accept. The student selection process is partially guided by a goal of a diverse student population. The school's enrollment at each grade level is held constant to maintain the 15:1 student teacher ratio.

Another attempt to maintain the greatest diversity within the student population is that no entrance examination is given to students before admission. However, several aspects of the school make attaining this diversity problematic. Perhaps the most limiting factor is the tuition, which approaches or surpasses (depending on the grade level) two thousand dollars per school year. Additionally, the transportation requirement also serves to narrow the population of students who can attend. While the Principal expressed a desire to have a population more congruent with the city's population, constraints in operation prohibit such diversity. In spite of the school's
efforts, there remain fundamental differences between the students at the Laboratory school and the city's population:

**Principal:** Now one difference in our population and and [sic] other public school's population is that we have tuition and they [families] have to provide their transportation. So that does make our population a little bit different from [the] parish's. Ah, our students often come from families who value education more and are out looking for an alternative. So that is a built in factor we can't change but . . . we don't seek out just a certain kind of student. . . . Ah, we do tend to have a little bit higher level of motivation. (P 76)

The Laboratory School fills a number of formal roles. These include student education, teacher education and preparation, educational research, in-service presentations, and serving as a "model school" demonstration center. However, as the principal points out:

**Principal:** The goals of this school include only one goal that relates to the students that go here. We have, you know, we will do the best job that we can educationally for the children that are here. . . . But that's only one of the [roles] of the school. (P 75)

The Biology II Class

Physical Appearance

Ms. Hurston's Biology II class has helped to fulfill several of these roles. In this class Hurston simultaneously educates students in biology and one student teacher in science teaching as she participates in educational research. This Biology II class is held on the bottom floor of the U High wing. When I first entered this class, I knew immediately that this was a biology classroom. Encircling the room on three sides are laboratory benches. Those benches and the walls beside them are covered with biological educational materials-things that are alive, things that depict life, or things that are remnants of that life. Aquaria serving as cages for mice and other rodents line one wall. Beside these cages are dried carapaces of horseshoe crabs. Across the room I can see bones from cows, shells from tortoises, a hornet's nest, microscopes, and aquaria housing small fishes. An androgynous model of a human torso stares at me, its organs and musculature exposed. As I probe, I find one plastic container filled with
debris and containing a colony of meal worms—a favorite laboratory animal of biology teachers everywhere. Toward the front of the room is a large aquarium which until recently had held an adult grouper and a plecostomus. (To the sad dismay of many of the students who had grown up with them, these fishes died at mid-year.) The aerator for this tank is somewhat loud. This constant gurgling and the sounds of mice and gerbils moving in their cages are strangely soothing in this biology classroom.

Covering the walls of the room are posters. These posters advertise famous zoos or depict endangered species and others explain animal classification systems (i.e., "The Animal Kingdom," "Protists"). I attended class for several days before I noticed the alligator head hanging over the doorway to the teacher's office.

The rectangular room is lined on one side by windows overlooking the front yard of the school. While these windows can let in a great deal of light, they also allow for long dreamy glances during Louisiana's massive thunderstorms. The desks, arranged in four rows, face the teacher's desk and blackboard in the front of the room. A television, overhead projector, and video recorder are in the front right corner. A space in the back of the room bounded by a set of long collection drawers remains free for lab preparation.

In many ways the classroom reflects much of the rest of U High. It is orderly, but worn. The light green paint on the walls is somewhat faded, but little of it can be seen because of all the classroom materials. Nothing in the class stands out as new except for an occasional poster or graphic found along the walls. The wood on the students' desks has uneven grooves etched by age, wear, and students' pens. However, like the larger school, it holds the promise of much activity. The obvious wear seen in this room signifies that these materials have been used by hundreds of other students. For me, the combination of biological materials, worn desks, mice, and blackboards is immediately comforting. This room reminds me of many other rooms in which I learned to love biology.
A Typical Class Period

On a typical school day, I enter this room just before fourth hour at 10:30 A.M. Ms. Hurston is already here, walking about the room, and setting up laboratory materials in the back. I speak to her quickly and take one of my usual places behind of the rows of seats. Hurston is a middle-aged woman, with short brown curly hair that is graying at the temples. She is wearing jeans, a red checked shirt, brown leather flats, and a large gold necklace. Often her jewelry takes the shape of animals such dolphins, salamanders, or frogs. The overall effect is of a casual neatness. Hurston is animated as she speaks. When she is deeply involved in an explanation, she stands in front of the class and takes off her brown reading glasses and waves them around her head as she looks at a student. Her speech remains the same whether it is directed to a student, a class, or an adult. She speaks rapidly, and her meanings are punctuated with humor, cynicism, laughter, and quick smiles. She often can be seen placing a hand on top of her head as she thinks through an answer to a student's question.

Joe Ellen sits beside Ms. Hurston who is reading over a calendar. She is Hurston's education student. She is working on her Master's Degree in biology education and is interning with Hurston for the year. Joe Ellen is a small woman in her mid-twenties. She is the only member of the class who is of African-American descent. She typically wears her straight black hair pulled off her face. Joe Ellen's face is very animated, and she both smiles and frowns quickly as she speaks surprisingly fast given her Mississippi accent.

Just before the first bell rings, Ms. Hurston places a Farside cartoon on the overhead. Then she sits behind the large front desk and looks over her reading or quickly grades some papers. Students begin entering the room from the front door soon after the first bell rings. The first students to enter are usually Bob, Calvin, and Jean. These juniors place their books in their favorite seats in the back of the room and walk back up to the front to make friendly conversation with Ms. Hurston and Joe
Ellen. As the other students enter, they walk toward their desks, but few of them sit. Instead, most stand and talk with their classmates. Day after day, most students return to the same desks although no seating has been assigned.

Soon the second bell rings and the kids come closer to their desks, many of them sitting down. Hurston asks the students all to have a seat so that Joe Ellen can take the roll. This movement is accomplished with a little talking. There are 12 juniors and 11 seniors in this class. Ten of these students are boys and 13 are girls. There was one more girl in the class who left at the end of the first semester, while explaining that her academic schedule threatened to overwhelm her.

The formal class begins with Hurston reading the "What is it?" question that is written on the side of the front blackboard. Each day the question changes, and it is accompanied by the answer to yesterday's question. After Hurston reads the question loudly to the class, several of the students call out possible solutions. These suggestions can range from comical to very well thought out.

After this brief discussion, Hurston launches into the topic for the day. The topic for discussion is an article on dinosaur extinction that the students read yesterday. Many students respond easily to Hurston's open-ended questions, often calling out answers without being formally recognized by the teacher. During the class-wide discussions, most students are attentive, even if they are not overtly participating.

There is little side talking between students, with the exception of a nucleus of juniors who sit together in the back, left-hand side of the room. This group includes Bob, Jean, Philip, Raistlin, and Calvin. I came to refer to them as the "trio+2" in my field notes because their actions so often drew my attention to their corner of the room. Most side talking that occurs in this class can be traced back to this group. Listening to their conversations, I could often hear them make references to the material the class was discussing. However, these references are often tangential and laced with a great deal of humor.
Cultural Themes

As my research focused entirely on this class, I considered the larger school only as it affected the students of this class. In regard to some points, I view the two, classroom culture and school culture, as synonymous. But I am sure this was not always the case. Class culture and school culture are profoundly related, but they should not be equated on a wholesale basis. In many ways, Ms. Hurston and this particular group of students had their own means of negotiating meaning. These ways were certainly affected by the school context, but my emphasis will be on the classroom. The next section will explore the major themes I have come to recognize as important in understanding the culture of this biology class.

Talking Academic

One of the fundamental themes through which I understand this class is termed Talking Academic. Borrowing from Lemke’s (1990) book, Talking Science, I use Talking Academic to refer to the ease and frequency with which these students assumed the mannerisms and implicit habits which characterize current academic discourse. For me, these habits are best signified by the use of academic language, both in verbal and written communication. Another characteristic of current academic discourse is an acceptance juxtaposed with questions, that is, Talking Academic includes an acceptance of the importance of the formalized knowledge of school along with a questioning attitude toward this knowledge.

An example of Talking Academic is signified by an excerpt from a whole group discussion held early in the school year during the unit on dinosaur extinction. Here, the teacher asks the students to compare various aspects of the natural sciences:

**Hurston:** So how does paleontology differ from the here and now of biology?
[The students do not hold up their hands in response but rather they call out answers from their seats.]

**Jesus:** It's a new science.

**Calvin:** Because they have more recent discoveries, with new technology.

**Anne:** No, but they discover new things in chemistry all the time though, like new elements.
Jean: Yeah, like Calvin said, they get one piece of evidence and that changes everything.
Philip: It's not a new science but an evolving science.
Grady: They have to work on clues; they can't go out and test things. It's more guesswork. They can't be sure of what they know.
H: So they operate more like detectives?
Bob: It could be the most misleading science. They can't check things. Other sciences have a lot of facts behind it.

This is one of dozens of such discussions. These are characterized by the teacher asking the students to draw from several areas of their knowledge. The students' participation is voluntary. A reading of the transcript reveals that the students are listening and thoughtfully responding to one another's comments. These students are participating not in a closely directed dialogue, but they are learning to participate in an academic conversation. They are Talking Academic.

I have identified three emergent codes students use in the process of Talking Academic: expectation, competition, and innovation. The first of these, expectation, is readily apparent. U High is considered to be a "college prep school" by almost all of its students. The large number of courses available providing advanced placement credit in colleges and opportunities for concurrent enrollment with the university signify the U High's role in preparing its students for college. The school is successful in this regard. The guidance counselor explains that 95% of all seniors enter four-year colleges or universities.

In a survey, each of these students in the Biology II class expressed their expectation of attending a university after graduation. The majority indicated out-of-state universities as possible choices. Sixteen of the 24 students in this class indicated in a survey that they wanted to become doctors, veterinarians, scientists, or engineers. Others were planning for careers in law or business. (These expectations may not simply originate with the school, but also from these students' families.) Almost all students come from homes where at least one parent has a college education. These students have an educational legacy to plan, prepare for, and expect a college
education. One sign of this preparation is the very regular daily attendance of students in Ms. Hurston's class. These students expect to succeed in academics. Of the four students I asked, not one had seriously considered what they would do for a living if they did not attend college.

A second code in the theme of Talking Academic is the code of **competition**.

Late in the school year I spoke with Tyler, one of my four interview participants, about the ranking system for students:

**SD:** What's your class rank?

**Tyler:** I'm like . . . or something like that.

**SD:** Uh, uh. [Yes] Ahm, it's important to me I think to know that you all know that. Why do you think that you know that here?

**T:** 'Cause it's so competitive here.

**SD:** Yeah?

**T:** 'Cause everybody's so smart. . . .

**T:** But my class number, it used to kind of matter, like when we first started getting our transcripts and seeing what number we were. Yeah, it matters. You want to be higher than your friends. [Small laugh]

**SD:** So you talked about it? Y'all actually sort of talked about your class rank?

**T:** Well you know you get your paper with it on it and, you know, you say, "What's yours? What's yours?"

**SD:** Uh, uh. [Yes]

**T:** You always wanted, well I do want to be higher than my friends. (C 252)

Tyler is not alone in her sense of academic competition. Students in this class constantly compare grades when papers are passed out, with some of the junior boys gloating if they received a grade higher than their friends. Frequently I could hear students sharing their overall grade point averages, ACT, or SAT scores with one another. I was surprised as I listened to casual conversations to find that these students knew the names of many students throughout the other schools in the parish who excelled in a particular subject. Why is there such a strong sense of competition in these matters? Another interview participant expresses this:

**Meredith:** Grades really, really mean a lot. Ahm, I found that out, that stuff like, [if] I had a 4 point, instead of a 3.977, I probably would have a [university] scholarship. (A 273)
The code of competition also surfaces in the actual form of classroom discourse. Often discussions in Ms. Hurston's class become student debates. In these "debates," as they are described by Lemke (1990), one student directly responds to a comment made by another. These debates typically include the overt participation of the boys in the class. While girls are not vocal in these sessions, several can be heard participating from time to time. (For an expanded discussion of the effects of gender in the classroom, see the section on Discussion Participants in Chapter 5.) Here, one student tries to discredit a statement made by another:

[Ron, a shy junior, has taken his turn in reading his critique of a scientific journal article standing in the front of the class. As soon as he finished, Philip, a junior boy sitting in the back of the class, raises his hand quickly, wagging it in the air.]

_Hurston:_ Yes, [addressing Philip] you have a comment?

_Philip:_ Yes. This is for Ron. Did they use the sampling technique described in the article of yesterday, like the 1-10 technique?

_Ron:_ (Long pause) I don't know.

_Philip:_ [Long pause, with eyebrows raised and hand to chin] Did they use anything?

_H:_ [Looking at Philip] What were the other techniques, Philip?

_He hesitates, gives an exaggerated shrug, and the entire class erupts in laughter.] (F 164)

I recall this as being a humorous exchange. Philip often initiates these sessions when others are presenting their ideas to the class. Like this one, his comments are often accompanied by exaggerated gestures—the raised eyebrows, hand to chin, a lowered voice, and a dramatic pause before speaking. He not only has learned to participate in academic discourse, but he also has learned this lesson so well he can mock its characteristics. The teacher plays an essential role in this mockery by making Philip the real brunt of the humor. Over the school year, I came to anticipate such mocking sessions during student debates whenever the students were festive. While these sessions had a variety of participants, none could carry them off with Philip's comical aplomb.

The final code in the theme of Talking Academic is **innovation**. The administration, faculty, student body, and parents have come to anticipate innovative
teaching to occur in this setting. This is provided structurally through the formal requirements for a teaching position at the Laboratory School. These requirements include a master's degree or higher, a state teaching certification, and at least three years of teaching experience. In addition to these formal requirements, the current principal has some specific characteristics in mind when selecting teachers:

**Principal:** I'm looking for people who I sense will work well with students, and work well with parents, and will work well with the college. I'm looking for people who are very creative. I'm looking for people who want to be something else rather than just a good, average teachers. . . . I'm looking for people who, who want to be leaders. . . . And very much so people who are ah self sufficient. . . . If I ever hire someone and the only way that, that they will do their best work is if I'm checking on them frequently or supervising them pretty closely, or visiting them frequently, then I've hired the wrong person. I'm looking for self starters. . . . I don't hire Indians, I hire Indian chiefs.

(P 77)

The result of this selection process has formed a faculty that has received substantial state and national recognition for excellence in teaching. Two teachers have been named Presidential award winners for Excellence in Teaching Science. Three teachers were named Presidential award winners for Excellence in Teaching Math. One teacher was named Discover Magazine's Science Teacher of the Year.

The codes of expectation, competition, and innovation each relate to the theme of Talking Academic. There is an interaction with each of the cultural forces underlying these codes. This interaction provides a synergy so that the education received by any student is enhanced by the students around her/him. This is a complex relationship: the same students who help one another academically are also in competition academically. This is not a school where poor performance is a form of cultural currency. As Ms. Hurston states, "It's not cool necessarily to be the dummy that sits back in the back of the room." (P 66) Instead, excellence in education, the ability to Talk Academic, is noticed, envied, and sought after. However, after reading the first draft of this chapter, Grady a senior boy, provided some additional insight into the theme of Talking Academic. He explained that at U High "there is a fine line we
[students] walk between talking academic and talking too academic. There's this real subtle line, a window. You can't be stupid, but you can't take yourself too seriously either." (5B 322)

Toward the end of the school year, the students became tired. This was particularly true for the seniors.

Tyler: [Tonight] I have about 500,000 physics problems to do and I have a big unit English test on about 5 stories plus romanticism and existentialism and all that. And I haven't looked at any of it, any of it. . . . And I'm not going to stay up late. I don't care. At this point I don't care. Who cares? Why even care? It doesn't make any difference. (C 244)

Even for these students, there are obvious emotional limitations to what they want to accomplish in school. Like most social realities, the synergistic quality of U High is not a constant state.

A Small Town School in an Urban Setting

SD: Since I've been here I've gotten a real flavor, this [U High] is almost like ah a neighborhood school used to be. . . .
Principal: Or a small town school.
SD: Yeah, yeah.
Principal: Well it is in some regards, and it's not in others. [Murmuring] Well, I guess you could say that we're trying to be a small town school in an urban setting. (P 72)

The previous conversation with the principal identifies the second theme through which I understand U High. This theme, being a small town school in an urban setting, allows me to understand much of the social interactions of the students and teachers in this class. What is meant by "being a small town school?" For me, this includes a strong sense of community juxtaposed with a strong sense of the independence.

With each of the four sets of parents I spoke with, community or a sense of "family" was cited as an important attribute of U High. Several students, one in Hurston's class, have parents and grandparents who attended the school. Certainly, a community atmosphere is enhanced by the small size of the school. Having so few students, the principal knows them "by names and faces instead of numbers" and this
knowledge can be used for "keeping kids on track." (P 71) Teachers too are well acquainted with their students by often having the same students for various courses during their high school years. This year Ms. Hurston had previously taught the juniors in their Biology 1 class. Brian discusses the positive results of this relationship:

**Brian:** When you get to know the teachers better, ... it is easier for them to instruct you when they know what you're looking for.” (B 3)

The stability of the student population has a considerable influence in creating a sense of community. Students in Ms. Hurston's class know one another very well. Many students have attended the same school since first grade. After reading the first draft of this chapter, Jean, a junior girl in this class, suggested that I had omitted a key aspect of the school's community. She explained that there is a great deal of interaction between students of various grade levels, "We [juniors and seniors] all get along and do stuff together." (5B 322)

The school attempts to foster this relationship by arranging several school events. These events include a retreat for the senior class held in the fall, a "spirit" day when each grade works together with one other grade for a service project for the school, and a winter formal which is held on the school grounds and includes all members of the high school. This close relationship translates into different classroom behaviors. Students in Hurston's class were often very tactile, touching one another on the shoulder as they spoke and playing physical games before the beginning of class.

Another result of this sense of community is described:

**Hurston:** I think that in many cases they [the students] are very open to kids coming in. I don't think they necessarily shut them off. I don't, I know I don't see it from the students' perspective, but I don't think it's as bad as a lot of people make it out to be. ... I don't see this school being that cliquish. I see the kids as being basically pretty friendly. (H 66)

In part I agree with Hurston's assessment. In laboratory situations, while students had favorite group members, these groups were fluid with group members often changing. Students seem to talk with everyone, although to some class members with more frequency than others. Students who didn't seem to be exceptionally close knew a lot
about one another's personal lives. However, from the students' perspective, cliques are an obvious part of schooling:

**Tyler:** It [this school] focuses a lot on social, social things. If you are not you know, if you are not in the cool group, then you are pretty much nowhere.

**SD:** So it is cliquish?

**T:** Yes! (C 254)

After reading an early draft of this chapter, the students initiated a discussion about the cliques at U High. Some students, like Tyler, felt that cliques were a major social force at U High. Other students disagreed. While the "strength" of cliques is a very relative judgment, I feel some meaning came be made from this conversation. Grady pointed out that students who have attended U High all their lives, like Tyler, felt that students in different social groups were very isolated from one another. However, students who have transferred here, such as Ginger and Stephanie, felt that the cliques at U High were relative mild to others they had seen. Ginger explains that "The cliques interact with each other here a lot more than at other public schools." (5B 324) In the end of this discussion, we decided that it was probably true that the students' social groups at U High were not as strict an isolating mechanism as is true in other schools. However, students had differing perceptions of these groups based upon their histories in other schools.

The community atmosphere of the school is contrasted to the emphasis placed on the independence of the individual. Hurston explains that one factor she particularly likes about U High is the independence it fosters in its teachers.

**Hurston:** I like that you have a lot of control over what you teach. You're allowed the freedom to do what needs to be done and teach the way you need to teach. (P 42)

One parent explained to me that the school also attempts to foster this development of the individual in its students. This was one of the reasons that all four of her children attended the Laboratory school:
Parent: I thought it [Laboratory school] gave a sense of self esteem. . . . I think this school is very good about giving children, all children who are good at different things, a feeling of self esteem. (B 306)

Toward the end of developing the individual, the laboratory school has a "point system" established. In this system, no one student can hold an inordinate number of leadership roles in the school. While this system is controversial, even its opponents agree that is has the attribute of allowing all students the chance to develop leadership skills.

There is an interesting tension between the community and independence aims of the school. In this passage, Tyler explains that while she is part of a community of students, she feels she must be able to give something back, to reciprocate:

Tyler: You ask your classmates to help you [with math homework] and it's just kinda', "Can you help me please?" [Laughs.] I feel so guilty. 'Cause nobody wants to help people that don't know anything. You know? (C 9)

One of the end results of this "small town school" atmosphere is a feeling of responsibility which develops in the students and their parents. While the recognition of responsibility is typically thought of as a positive trait in a teenager, it also can take the form of harsh criticism when the teaching does not meet the degree of innovation the students expect.

SD: The seniors really feel like they can . . . have a hand in getting rid of someone [a teacher they disapprove of]?
Hurston: Yeah. That's a perception that you know the administration [strongly disagrees with] when they hear . . . . But the seniors really think they do have that kind of power and they will make every effort to do that if they think the situation warrants it. (P 28)

So the theme of "being a small town school in an urban setting" is composed of the interrelated codes of community, independence, and responsibility. These themes serve to describe many of the social and political actions of the participants in the class and their orientation to the school.

The Myth of Uniformity

SD: Do you still like it here [U High]? Or?
Tyler: It's too small.
SD: It's too small.
T: Yeah. So. [Pause]
SD: And that smallness bothers you because you don’t get to meet anybody new?
T: I don’t know what it is. I don’t know what it is. You don’t get to see what’s really out there. . . .
SD: How do you think [other] schools would be different from this school?
T: You get to be with so many different kinds of people.
SD: Uh, uh. [Yes]
T: And to see what it’s really like out there.
SD: Uh, uh. [Yes] Do you think it's kind of left you ill-prepared for ?
T: Ah, I mean, it probably hasn’t. It seems like I. You’re just so enclosed and you don’t experience the real world. So I don’t know. It’s just so sheltered. (C 3)

The final theme through which I understand this school is that of Uniformity. Despite the stated goals of the administration, this uniformity is best reflected in the student population in terms of racial and class makeup, family background, appearance, goals and classroom behavior. Most students in Ms. Hurston’s class are Caucasian and two girls are of Asian descent. This makeup is an accurate reflection of the student population of the high school. However, this racial makeup is far different from that of the surrounding city. Additionally, there is a uniformity in class backgrounds of the students. As Meredith explains, students at U High "come from, you know, middle to upper class families." (A 274) This perception is echoed by Tyler who explained to me, "there are no lower class families here." (C 258) It is obvious from the principal’s "Indian and Indian Chiefs" comment found in the Talking Academic section, that the administration, like many of the students here, is not overly familiar with working with marginalized student populations.

But perhaps the most striking example of uniformity is in the appearance of the students. Their styles of dress are remarkably constant. For a large part of the year, most of the class wears shorts, tee shirts, and tennis shoes. Only during the coldest part of the winter does this uniform change to heavier clothes. Fall brought out black and yellow U High letterman jackets. (Although these jackets seemed more for show as the junior boys wore them in the already too warm building.) Some students always wear
long pants, typically jeans, but they are in a minority. On any given day the "look" of the students in this class is extremely casual. Students who fall outside of the informal "dress code" are "talked about." One example of this is seen in Ms. Hurston's class, When Brian and a classmate began to wear unusual leather sandals they were given the nicknames of Moses and Jesus. Tyler explains the social pressure that maintains the uniform appearance of the students:

**Tyler:** We all seem to be alike. That's because of the pressure. If you wear something different, if you wear something different, it's like everybody talks about it. . . . People notice that kind of stuff. Anything a little bit different. . . . Yeah, if you get, if you dress up, people are like "What are you looking nice for today?" (C 260)

After they read the first draft of this chapter, several students expressed dissatisfaction with the meaning they took away from this section. Priscilla, a thoughtful junior girl, explained that the reason the students looked very similar was due more to their shared middle-class backgrounds than the operation of some social pressure. She reasoned, "I don't wear these polos [shirts] because somebody makes me. I wear them because they're comfortable. Nobody goes shopping and thinks about what people are gonna' say." (5B 323) A brisk discussion followed her comments. Grady explained that while Priscilla may not feel pressured, other students may. But he went on to point out that the homecoming queen this year was a girl considered to be the "strangest dresser in her class." (5B 323) There was no consensus drawn from this debate, simply the notion that the social pressure operating in U High is not felt universally.

Perhaps due to this relatively homogeneous student population, the **day-to-day activities** of the school are also characterized by uniformity. As Brian expresses, "It's pretty much the same everyday." (B 266) While this aspect of the school is simultaneously bothersome to Tyler, as signified in her words which opened this section, it is attractive to many of the parents which send their children here:

**SD:** Why did you send your children to the laboratory school? . . .
Brian's mother: Stability. Once a kid gets ah in there, it's like they're part of it and they are there as long as they chose to be. I wanted a situation where my kids could get to feeling like they were knowing where they were going and they had a future and it wasn't going to change every three, four, five years or whatever. (B 306)

Other parents remarked that they chose U High because it reminded them of the schools of their past-small, familiar, and safe. Stephanie's parents chose to send her here only after they were disturbed by the tall wire "cage" that surrounded a near-by magnet school.

Perhaps it is the voice of the parents that provides the most insight into this theme of uniformity. The members of U High's community are attracted to uniformity in the face of what they perceive as the tumultuous conditions of education found elsewhere in the city. U High becomes to these parents a school where their children can complete a "top notch" education in safe, familiar surroundings. As described by Tyler's words:

Tyler: We're sheltered here. I mean we have, it's like we have this one way of thinking. [Pause] And we're supposed to kinda' think that way. (C 259)

Like Tyler, other students seem to struggle with the sense of Uniformity. It is the struggle which makes the theme of Uniformity more myth than substance. When I invited the students to select their pseudonyms that would be used in this study, students replied with names such as Jesus, Juanita, Moses, Raistlin, and Ferdé. Some of these are the names the students used in their foreign language classes, and some names are nicknames. But the students chose to be known in the study through these names. I feel that this selection signifies an attempt to be seen as something other than homogeneous and monolithic. These names are markers of the students' struggle to be individuals.

Another marker of the students' desire to be individuals is seen in their classroom efforts. A small group of students does not always meet up to the standards others expect. Meredith explains that not all students at U High are trying to obtain the
best education possible for them. Many are willing to "come to school everyday and you know, do nothing, or do the bare minimum." (A 273)

If some part of my description fails to allow the reader a useful understanding of the students in Hurston’s Biology II class, it is on the topic of student individuality. In our discussion of an early draft of this chapter the students’ most serious concerns had to do with this topic. As might be expected, they perceived the members of their class as being distinctly individualistic. Several students in the group pointed out that my description failed to underscore that individuality. One student mentioned that they each have very different personalities and personal interests. Priscilla reminded me that while the students all have similar professional goals, they have different reasons behind the quest for these goals. The discussion reawakened me to the knowledge that while generalizations can be useful, they often do the analyzed group a disservice.

**Summary**

**Principal:** Ah, if you’re going to be around here for a while, the kids would pretty much look like regular kids. They’re not exceptionally mature for their ages. . . . They don’t all do the right things at the right times. They’re not all doing the best they can academically. We have a good spread of that . . . and an interesting group of kids. (P 71)

In some respects I now agree with the principal. I can see a great deal of diversity in these students. But that recognition came only over time, after a great deal of study. Initially, I did view this Biology II class as a monolithic group of smart, ambitious, middle-class, and motivated students. But through watching the class and talking with students, I did begin to recognize them as individuals. I can now see that this group of individuals have some commonalities.

What does this group of students have in common? What is the culture of this class? Many practical implications of that culture will be discussed in the next chapter. But some of the more universal characteristics include the value the students place upon academic knowledge, academic practices, and the processes of education. Much of this value may actually be the result of the students’ goal of obtaining a particular
kind of profession as a result of what they perceive as proper schooling. The students value the individual in her/his attempt to gain academic knowledge, but that individualism is tempered with a recognition of the need for the individual to make contributions to the greater community. Students learn, but students should help others to learn. Additionally, students are responsible for helping keep U High a place where this optimal learning can occur.
CHAPTER 5
THE TEACHER AND HER TEACHING PRACTICES

The Teacher

The teacher's office is located off the front of the classroom. The small office is crowded with school material interspersed with more personal effects. The room contains an enormous amount of books stacked in piles on the floor, the desk, and falling out of over-crowded book shelves. These include a mixture of practical biology classroom texts and catalogues (biological supply catalogues, Gerbils, and Project 2061: Science for All Americans) interspersed with literature (such as Eco-Fiction, A Sand County Almanac). Then I notice the desk. It is difficult to see its surface because of the volume of papers it holds. On the walls surrounding the desk, pictures are arranged showing Hurston's own children and many of the children she has taught.

The office reflects much of what I think of when I think of Paula Hurston: children, biology, entertainment, hustle. She is a woman of diverse interests and abilities. She feels that one of her strengths is her ability to "access a lot of things... I have the ability to pull from a lot of different areas." (P 45) This ability to draw from different disciplines stems, in part, from Ms. Hurston's wide educational experiences. Her undergraduate degree was in biology and chemistry. Later, she became simultaneously certified in science education and received her Master's Degree in this area. She is currently working on a second master's degree, this one in natural science, by taking one evening course each semester.

Even while teaching and working toward a degree, Paula remains very involved in professional organizations. She has been on the board of the National Association of Biology Teachers. Associated with this organization, Paula has been the regional coordinator and state representative for the Outstanding Biology Teaching Award and has been involved with the long-range planning committee. She is also a member of
the Louisiana Science Teacher Association, and she was a founding member for the
Louisiana Biological Educators. In addition to these organizations, Paula often
presents papers at professional conferences and workshops. She has participated in an
internship sponsored by the Howard Hughes Medical Institute by working with a
zoologist during the summer months. She was selected to attend an outstanding
biology teacher's symposium sponsored by National Science Foundation. She often
provides workshops in biology teaching techniques for other teachers in the parish.
More closely related to this study, she participated in an evolution education workshop,
and she attended the Evolution Education Research Conference during the year of the
study and published in the proceedings (Good et al., 1992).

When one considers all of these activities, a picture of a very motivated, well
informed, and "driven" teacher emerges. (P 45) Ms. Hurston goes beyond the
minimum amount of work expected of her and seeks additional experiences because:

**Hurston:** I'm always learning something new. That's one of the, the
exciting things, that I'm always provided the opportunity to learn about
new things, and the impetus to learn about new things, and the reason to
go and learn something new. . . . And that's what keeps me alive and
keeps my teaching from being [she moves her hand in a straight line].
(P 43)

Ms. Hurston acknowledges that she is simultaneously "laid back" and "driven."
In my observations in the classroom, she continually has a friendly demeanor. In her
discussions with students, she often sits on top of the front desk swinging her legs in a
carefree fashion. She decorates her classroom for almost all holidays, and she brings
small treats for the students, typically candy which they all quickly consume. At
Christmas she wore an elf hat and a red nose. In our many conversations, Paula is
talkative, helpful, and full of amusing stories.

It is difficult to adjust this leisurely picture with the other in which Paula is in
constant motion. But aspects of both these portraits of Paula are there, intermingled:
the presence of one feature making the other more effective in the classroom. How is
this constant pull sustained?
Hurston: I'm busy enough in my own little corner of the world that I, I don't go out [of the classroom]. I don't sit in the lounge a lot. I just never have got that kind of time. . . . I have always read while I was eating lunch. And maybe that is such an ingrained habit that I feel real stressed out if I don't read something during the day. I do find I have to have a little time by myself during the day. Or I just, just really (sighs). I love people, I like being around people, but I need a little bit of alone time sometimes during the day to keep me mentally healthy. (P 29)

One way in which the dichotomy of driven and being laid back asserts itself is in Paula's fluid teaching style. She is always looking for:

Hurston: A better way to do it. I'm always changing things. So you know, every time I learn something new, that means that goes in, and other things get rearranged. (P 100)

All of my experiences watching Paula Hurston in the classroom made explicit her love of the ambiguity and uncertainty inherent in the discipline of biology:

Hurston: It's kinda neat to think that there are realms that we don't yet understand and know about. (P 3)

She is also a woman who is firmly committed to the project of teaching:

Hurston: [Teaching] has an impact on a lot of people's lives, and you can have a real positive influence on kids. You can impact their lives in a lot of ways. I like the challenge involved. There is a lot more challenge to teaching than just about any other job I know of. (P 43)

Hurston: Teaching consumes me, it really does. I spend a tremendous amount of my time out of the classroom thinking about the classroom, doing things related to the classroom, learning about things for the classroom. (P 100)

Hurston's Teaching Philosophy

Paula Hurston's general views and beliefs about teaching are deeply rooted, and she articulates them in a somewhat fragmented fashion. However, there are themes which continually emerge as she talks about teaching. These themes reflect her beliefs of effective teaching and theories of student learning.

Close Student Teacher Relationships

Ms. Hurston's first concern is maintaining a close relationship with her students.

Hurston: How do kids learn? . . . You know, I've always said that you can't teach them anything unless you can get them on your side. That's why I think teachers fail, because they do this big authoritarian, "You'll learn this because I said you'll learn this." So you [the teacher] have to
Building close relationships with her students is very important to Ms. Hurston, and she feels that it is this skill, "the ability to see from their perspective," that she learned from raising her own three children. (P 63)

Students' Interest

Intimately tied to this close relationship, Hurston explains that students must be interested in what is studied in order to learn. Hurston feels that she too should be interested in the topic in order to transmit that enthusiasm to the students. She "trades" on her close relationships with students to introduce them to the topics of biology. (P 23) Additionally, she attempts to present topics in a manner that is relevant and important to the students lives. She discusses real world applications of biology so that students can come to understand the value of information. Hurston understands that real learning, "not just memorization," is fostered only in the presence of students' interest. (P 61)

Prior Knowledge and Developmental Level

Hurston views prior knowledge and student cognitive development to be important controlling factors of learning.

**Hurston:** [Students] learn by experiencing it [the topic] and by tying it to their own personal experience. They have to have a knowledge base to base their learning on. (P 61)

She adds a Piagetian twist to this Ausubelian explanation, "They learn it when they are ready to learn it and not before." (P 61) Based on this hybrid learning theory, Hurston explains that even for seniors, topics should be introduced from the "ground up."

**Hurston:** You've [the teacher] got to make connections for them [the students]. You can't get too simple. Labs and activities and experiences. I use the same things with elementary school kids, middle school kids, and high school kids. And they learn different things at different levels. I always feel like I'm judged on how basic I can make [a topic]. (P 61-62)
Critical Thought

After watching a lesson on mitosis, Ms. Hurston spoke with the student teacher in charge of the presentation. She suggested that the student teacher would benefit from a change in the focus and goals of her teaching. Instead of emphasizing 20 important facts, Ms. Hurston suggested that she should emphasize a very small number of important concepts, "because if you're lucky you might teach those two or three things." (P 21) By decreasing her emphasis, Ms. Hurston believes this allows the students:

**Hurston:** to turn it around all different directions and look at it... Then they own it. Then they can do something with it. That's what I consider to be critical thinking skills, the ability to look at it, turn it around in all angles, and figure out what to do with it. (P 64)

Hurston's understanding of critical thought as the goal of instruction is very similar to the description of meaningful learning provided by Smith, Blakeslee, and Anderson (1993). These authors define meaningful learning of science as "coming to understand scientific ideas as they are used for their intended purposes, including description, prediction, and explanation of phenomena in the natural world." (Smith et al., 1993, p. 111). Hurston's "figure out what to do with it" includes the applications of scientific knowledge as described by Smith et al. (1993). Such applications require that the student go beyond the rote learning of material to application of that knowledge. While Hurston does not use the specific term, she is teaching for meaningful learning in her students.

Classroom Atmosphere

Toward these ends and in keeping with her close relationship with the students, Ms. Hurston does not establish herself as the authority in her classroom. Instead she views her role as "a facilitator, a motivator, a coach not a player." (P 49) She feels this gives her students the greatest freedom to investigate different aspects of a science topic. It is through these investigations that she feels students come to "own" knowledge.
Ms. Hurston believes that her equitable relationship with students places upon them the responsibility for their own learning. She expects the students to be active participants in class: she delights in a talkative, active class.

**Hurston:** I love it when they get to picking and arguing with each other and challenging each other on a fairly serious level. (P 33)

Ms. Hurston fails to understand students who do not take part. She explains that student side "talking doesn't bother me nearly as much as being quiet." (P 36) Because of this, she constantly manufactures situations, laboratories, discussions, or debates that will foster the participation of more of her class.

Just as students are responsible for their own learning, they too are responsible for their behavior in the classroom. Unlike many teachers, discipline is not a topic Ms. Hurston dwells on.

**Hurston:** I guess I trade on my relationship with the kids for discipline. Ah, they recognize that I am always fair with them, that I am always sensitive to their problems or whatever... And because of that, I guess I trade on it, in that I then expect for them to treat me fairly, and with respect. (P 23)

She acknowledges that discipline is not a large factor for any classroom in U High. This situation is magnified in her classroom where talking and movement are encouraged and discipline is "not to be worried about." (P 21)

Hurston designs her classes to promote student participation. This participation includes student interactions with materials, with the teacher, and with other students. While such classroom activities are congruent with the conceptual change teaching practices as described by Smith et al. (1993), the application of the conceptual change label to Hurston's teaching would be artificial. While familiar with the conceptual change theory as described by Posner et al. (1982), Hurston did not consciously design her teaching using this theoretical framework. But it is noteworthy to mention that Hurston has an intuitive recognition of the importance of student-student and student-teacher dialogues in the learning process. She recognizes that a student must relate her/his new knowledge to pre-existing knowledge, and this relation at times requires a
wholesale change of the student's prior conceptions. Hurston's teaching centers on the effectiveness of student dialogue in this process of change. While she does not cite Vygotsky's social learning theory, she has a recognition that much "real" learning is a social act. Thus, I am hesitant to label Hurston's teaching. However, many of her teaching practices can be understood when conceptual change is understood to be a social construction.

Hurston's Conception of a Good Teacher

**Hurston:** Uhm, a good teacher is just anyone who can inspire kids to care about learning something. Ah, not necessarily in the classroom. I mean, a good teacher is anybody who can forge the kind of relationship with kids that makes them either care about learning, or want to learn, or learn something unwillingly even. You know, it's. [Sighs] It gets beyond, far, far, far beyond content, into attitudes and you know the whole thing about wanting to make people into life-long learners. Make them care about things. Make them care about learning. Anybody who can accomplish that is a good teacher. (P 99)

The Biology II Course

Teacher's Description of the Course

Ms. Hurston has been engaged in science education research in the past. A portion of the students studied by Cummins (1991) were enrolled in Ms. Hurston's Biology II course. For this earlier dissertation, Hurston wrote a description of her course, and much of this description continues to hold true:

My major goal in planning my science course was to develop a curriculum to meet my dual objectives of preparing students for scientific careers and of developing scientific literacy in all students. . . . The usual Biology II course is a repeat of biology I on a high level, an anatomy and physiology course, or an AP biology course which is again biology I on a higher level. They all emphasize very structured, fact-based content with a lot of rote memorization. A number of researchers in science education have decried this type of teaching, stressing instead the need to teach critical thinking skills, process skills, cross-disciplinary information, and scientific literacy. The AAAS's Project 2061 incorporates many of the goals which I had included in my classes, and I was very pleased to discover the correlation. They stress understanding key concepts, being familiar with the natural world and with technology, and having a capacity for scientific thinking, knowing the strengths and weaknesses of science as a human enterprise, and using scientific knowledge and way of thinking in an interdisciplinary world. This fills the needs for both science and non-science majors in college, and for those who don't want to go to college as well. The National Research Council's *Fulfilling the*
Promise states that "The time has come to stop designing curricula by the process of serial dilution, in which the high-school course is a thin version of the college course, and the middle-school course is a thin version of the high school course". They suggest that the AP biology course "may not the soundest educational experience for students" who take a second biology course in high school. They recommend either a course in experimental science or what they call a "capstone" course. This course would include several modules which would integrate science and society issues and focus on current topics of interest. The students would brainstorm and research the problems and write reports giving alternatives, conclusions, and recommendations. They see the benefit of this course as "the educational reward to students in discovering interdependencies, complexities, dilemmas, ambiguities, and the need to synthesize information in designing solutions to society's problems" as well as developing "skills in reading critically" and giving "understanding that scientific inquiry is open-ended and that studying science is not simply reading and memorizing." I was really thrilled to read this, because that is exactly what my Biology II course is designed to do.

I began developing this course [seven] years ago. It has evolved over the years and continues to do so, and I include some input from the students on possible topics. The basic structure of the course includes an exploration into what science really is and how it is carried on, including experimental design, problem-solving activities, brainstorming, critical reading and thinking skills, library and reference skills, and laboratory skills and techniques. . . .

The class is rarely dull, and I'm not always sure which students will respond to which experiences, but they all find something which turns them on during the year. It's very important to set the tone from the first that they can express themselves freely without fear of being laughed at or put down by the other students or more subtly put down by the teacher. Sometimes the discussions get heated because they develop rather passionate views on the issues but with little 'monitoring' hurt feeling and anger can usually be avoided. I consider my students to be well on their way to scientific literacy, and they love it! (Cummins, 1992, pp.165-172)

Hurston's Goals for the Biology II Course

Hurston explained that she used many different instructional methods because she had several distinct goals for her students. She identified seven goals which influenced both the scope of her course and her teaching methods. These goals include: (a) to expose the students to the methods and goals of science, (b) to expose the students to the relationship of science to other disciplines and to other aspects of their lives, (c) to expose the students to topics of biology they might not have previously encountered, (d) to nurture students' interest and excitement in science, (e) to make the students scientifically literate, (f) to enhance students' abilities to critically
read, analyze, and question the findings of science, and (g) to familiarize the students with common laboratory techniques.

Which of these goals were more important in Ms. Hurston's course? The answer to this question varied with the unit being studied. Perhaps the two most influential goals of this course were the development of a sound understanding of the nature of science and the development of the students' abilities to think critically about methods and findings of science. Hurston was very concerned with helping students construct a firm understanding of the nature of science; that is, "the realities of how it [science] really does work and fit into their worlds." (P 15) She also fashioned much of her teaching around the goal of critical thought.

**Hurston:** That's what the whole course is designed to do anyway is to teach them how to look at things and think about them. (P 18)

**Instructional Units**

The course stretched over 151 days from the beginning of school until the seniors began their final examinations. (The course extended one week past this time for the juniors, but this period of instruction was not included in the analysis as the posttesting for the research had been completed.) Of the 151 days, the class was engaged in testing during seven days. The remaining 144 days were set aside for instruction. Approximately one and a half of these 144 days were used in testing for my research and student discussion of my research.

As shown on Figure 3, there were nine major instructional units in Ms. Hurston's Biology II course. However, Hurston's instruction did not proceed directly from one of these major units to another. Instead, these nine units formed the skeleton of the course, and total instruction devoted to these units included only 103 days of instruction. The remaining instructional time was directed toward topics outside of the instructional skeleton. These tangential topics were typically addressed through means of a laboratory or an outside speaker. Instruction in these topics seldom
Figure 3
Teaching timeline: The amount of class time spent in each major teaching unit and number of instructional episodes in evolution extended more than one or two days in succession. Additionally, Ms. Hurston often revisited topics weeks or months after the students' first introduction to the unit.

Figure 3 also oversimplifies Hurston's class in another way. Close consideration of the instructional topics reveals the blending of units. For example,
while several days were devoted to the discussion of the current conception of the
nature of science, the unit devoted to dinosaurs and theories of dinosaur extinctions
represented another means of demonstrating how science works. Therefore, the first
two units of instruction were closely interwoven, and it is difficult to separate precisely
where one unit ended and the second began. With this in mind, Figure 3 can be seen as
a rough generalization of the instructional topics of the course and their relative time
spans. (Appendix D includes an outline of the actual teaching materials used
throughout the school year.)

The first unit focused on the nature of science. For five days, the students
participated in laboratories, read news articles, and watched videos. Hurston's
intention for this unit was to acquaint students with the procedures of science, both in
experimentation and argumentation. Additionally, an analysis of pseudoscientific
topics was designed to help students begin to recognize the range and limits of
scientific explanations.

The second unit focused on dinosaurs—their behaviors, their evolutionary
beginnings and descendants, and the various theories of their extinction. For 10 days
the students studied dinosaurs through class discussions, videos, and readings taken
from an assortment of books, newspapers, and science magazines. During this unit
students saw how scientific theories currently in use have undergone revisions and
modifications. This unit stressed the tentative nature of scientific theories. By the end
of the dinosaur unit, students were discussing the merits and disadvantages of many
theories still currently under debate within scientific circles. In Lemke's (1990) words,
the student were learning to "talk science." Hurston designed this section to allow
students to understand the implicit rules of science and scientific argumentation. So
while the focus of the unit was dinosaurs, this material provided an excellent medium
though which students could get a glimpse of science currently "under construction."
The material selected for this unit stressed that science is a human endeavor, often accomplished by ordinary people who are intensely interested in a particular subject.

Throughout the year, portraying the current conception of the nature of science was a guide post of Ms. Hurston's class. Within each unit, the methods of inquiry and the products of that inquiry were analyzed by the class. This focal point was more obvious in the beginning two units, but later units clearly emphasized the nature of scientific inquiry as well (anthropology and evolution). So while the description of the following units will not stress this focal point, the emphasis of the nature of science was never omitted in Hurston's teaching.

One of the last aspects of the unit on dinosaurs included readings on dinosaur behavior. Hurston introduced students to the means scientists use to study behavior through fossilized remains, tracks, and traces. This discussion led easily into methods employed to study the behavior of living organisms. Through the use of many videos, journal readings, and laboratory experiences (both in the classroom, at home, and at the local zoo), students became familiar with the practices of the study of animal behavior. This unit occupied 19 days of instructional time. While the unit on animal behavior stressed the different methods through which primate behaviors are described, the various theoretical bases behind the behaviors were not emphasized. Much of the research the students studied included the voluminous work of Jane Goodall with the chimpanzees in Africa. Because of the nature of this and related research, many students became keenly familiar with the basis of primate behaviors and with humans' relationships to the other primates.

During the animal behavior unit, class-wide discussions established that most of the students had begun to recognize the striking parallels between the behavior of all primates, including humans. From this common recognition, Hurston launched into discussions of animal rights and animal conservation. This short unit lasted seven days and was begun with a discussion of the value of zoological parks. Several videos were
used to portray the benefits and drawbacks of the use of animals in experimentation. The bulk of the unit centered on student preparation for a two-day debate in which they had to argue for or against the use of animals in experimentation, education, industry, entertainment, and trapping.

The following two units were designed to prepare the students who were planning on pre-medical college educations. The first was a unit on genetic techniques. This six-day unit was centered on a three-day laboratory exercise in DNA electrophoresis. Students were given prepared DNA samples which they differentiated using gel electrophoresis. The materials for this laboratory were provided through the university, and the students were videotaped by the local public television station as they completed the laboratory exercise. Hurston related this technique to the concept of DNA cloning by the use of another exercise which had students participate in "mock" preparation of DNA clones for viral vaccines.

The anatomy unit was also designed explicitly for the many pre-medical students. For this 10-day unit, the students participated in dissection of a fetal pig led by Joe Ellen, the student teacher under Hurston's instruction. Hurston explained that this exercise allows students to gain experience in dissection and to decide if they enjoy this type of activity. Although the students were not required to dissect, each chose to do so. Students worked in groups of three as they dissected several organ systems. The students were responsible for the anatomy of these organ systems but not their physiology. The unit culminated in a laboratory practical and journal entry.

Evolution was the next unit following anatomy. Because Hurston's instruction in evolution is a focus of this study, this unit will be described in much greater detail in a following section.

The unit of microbiology techniques required 21 instructional days and was the longest unit of the course. Although this was a fairly comprehensive laboratory treatment of microbiology, only laboratory techniques were stressed; other aspects of
the discipline were not addressed. During this unit students gained many of the laboratory skills they would need in a college course in microbiology, including media preparation, sterile transfer technique, slide preparation and staining, and bacterial culturing practices. They also complete a series of tests on a group of stock cultures. These data were used by each laboratory group in the identification of a bacterial unknown which was the culmination of this unit. Hurston views this as an important unit because college microbiology courses often do not allow students ample time to refine their laboratory skills. She has designed this unit to allow her students a "head start" in this area. The identification of the unknown required the students to use reasoning skills to determine one answer based on their voluminous data.

The unit on anthropology comprised the final 15 days of instruction. Again, this was a laboratory intensive unit, focusing on the methods of physical anthropology as they are used to explain tentative evolutionary relationships of early humans. Students learned techniques which enabled them to determine the gender, age, and approximate size of an individual based upon measurements taken from skull and skeleton. The students also learned the applications physical anthropology has for forensic science, and they visited two forensic laboratories in the area. The unit culminated with the students proposing a human lineage based on four skulls by using both the techniques and theories they learned throughout this section.

As mentioned previously, while Figure 3 shows the nine major units of instruction, many other topics were addressed in the class. A scientist from the university visited for three days and helped the students with a neurophysiology laboratory. The students learned the basics of the physiology of vision through another laboratory experience. The topic of human behavior was addressed through a set of readings, and the students were responsible for completing their own experiments in this area. Throughout the year, the Ms. Hurston continued to emphasize the methods used in science through a series of laboratories designed to explain the fundamental
principles of scientific sampling, control groups, and data analysis. Even though nine major units of instruction were identified, many more topics were addressed in a more limited or fragmented fashion.

Instructional Methods

Ms. Hurston's instruction is very student centered, with the students expected to take an active role in the instruction on an almost daily basis. In a randomly selected sample of 20 instructional days, the main lesson activity relied on small group work for 55% of the days, the main lesson activity relied on individual group work for 30% of the days, and the main lesson activity relied on whole group work for 15% of the days. These statistics are congruent with Hurston's description of the course as "an exploration into what science is and how it is carried on." (Cummins, 1992, p. 172)

While she emphasized small group work, Hurston used several methods of teaching in her Biology II course. On any given day, typically two or three teaching methods were employed.

Hurston: I've got so many different goals and things that I want to, to accomplish with the kids that I bounce around from thing to thing just trying to accomplish different goals. You know, I don't see anything wrong with being somebody different everyday. (P 49)

However, some methods were used more frequently than others, and the most common or prominent teaching methods will be discussed in this section. Table 4 compares the most prominent instructional methods and their frequency of use.

Class Discussions

If we consider discussions to include any oral treatment of a topic, whole class discussions were used virtually every class day. This frequency is not reflected in the statistics for the main lesson activity because these statistics reflect only the main activity for a day. While discussions were rarely the main lesson activity for an instructional day, they were frequently employed by Hurston. The average whole class discussion was eight minutes in length and typically five or six short, whole class
discussions were held per week. Occasionally discussions were omitted from class activities, but only when an activity was continued from a previous day.

Table 4
Type and amount of use of the most prominent instructional methods in the Biology II course

<table>
<thead>
<tr>
<th>Instructional Method</th>
<th>Number of Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio-visual Presentations</td>
<td>20</td>
</tr>
<tr>
<td>Discussions</td>
<td>5 or 6/week</td>
</tr>
<tr>
<td>Examinations</td>
<td>4</td>
</tr>
<tr>
<td>Journal Entries</td>
<td>10</td>
</tr>
<tr>
<td>Laboratories</td>
<td>47</td>
</tr>
<tr>
<td>Readings</td>
<td>18</td>
</tr>
</tbody>
</table>

The most common discussions held in Ms. Hurston's room included teacher exposition, structured triadic dialogue, loose triadic dialogue, and student cross discussions. These categories are taken from Lemke's (1990) analysis of science classroom discourse. In this analysis, Lemke (1990) describes teacher expositions as an explanation given in the form of a monologue. In a triadic dialogue, the teacher asks a question, calls on a student to answer the question, and then proceeds to evaluate the student's answer. For the purposes of Ms. Hurston's class, I have further divided triadic dialogue into structured and loose categories. A structured triadic dialogue has several steps:

(a) the teacher asks a question,
(b) the student gains the teacher's attention either through raising hands or calling out,
(c) the teacher recognizes the student,
(d) the student calls out the answer, and
(e) the teacher comments/evaluates the student's answer.
For the purposes of my study, a loose triadic dialogue may have only steps a and b. The more formal steps are omitted in this type of discussion. The final common discussion in Ms. Hurston's classroom was a student cross discussion. In this exchange, the students speak directly to one another in reference to the class material with the teacher acting as a moderator or as an equal participant in the discussion.

The most commonly used type of discussion was a loose triadic dialogue. Although this type of discussion is informal, these discussions were often very successful in providing a comprehensive treatment of the topic. The success of these discussions was due to a high degree of student participation and engagement. Hurston felt her classes were very active in this type of discussion because of the friendly classroom atmosphere in which students could "express themselves freely without fear of being laughed at or put down" by the teacher (Cummins, 1992, p. 172).

The structured triadic dialogue was used less frequently by Ms. Hurston. This more formal activity type was used infrequently, normally during periods of low student engagement, (e.g., on the Friday of Homecoming). Hurston used this activity in an effort to focus students on the material under discussion. On the occasions when Hurston felt constrained into using this formal structure, she explicitly asked the class the source of their distraction. They would talk briefly about this, (e.g., a very difficult test in another class), and then the discussion would revert back to biology.

Hurston used a teacher exposition format of discussion to present procedural information for a laboratory or other exercise in the beginning of a class period. However, even within these guarded conditions, Hurston's monologue often changed rapidly into a structured triadic dialogue. An example of this change was seen in her presentation of the working of an autoclave in the microbiology laboratory. Hurston began the explanation using straight exposition which required no input from the students. Within three minutes of this presentation, Hurston soon changed the format asking questions such as:
Where would I put the water?
What's the water for?
What's the steam for? (F 504)

Once again, we see Hurston's attempts to remove herself from a position of extreme authority in the classroom while she engages the students in the classroom presentation.

The final commonly used discussion strategy was student cross discussions. These cross discussions involved students responding directly to another student in a whole class discussion. Often, these cross discussions would take the form of one student arguing with a point made by another student. These debates have been described in the earlier section on classroom culture. In the cross discussions, Hurston served as a moderator, ensuring that the participants' comments could be heard by the entire class. The following is an example of a student cross discussion/debate:

**Hurston:** What did you think of Jane Goodall's video ["So Like Us"]?
**Grady:** It was a side show. She choreographed the whole thing to fit her little script.
**Calvin:** Yeah, she did that a little. But she also showed that the chimps can feel what we feel.
**Bob:** But can they? Can they feel what we feel?
**Philip:** I don't think we should be [slowly] anthropomorphizing [sic] them.
**Hurston:** What?
**Philip:** I don't think we should be [slowly] anthropomorphizing them.
**Calvin:** I wonder if they can think ahead? Can they plan things like?
**Priscilla:** Yeah, we say that. I mean they showed that the gorilla could. (F 197)

The significance of this discussion is that students were addressing one another, not Hurston. This was a true cross discussion, with the students in an equal position of authority as the teacher. Lemke (1990) remarks that teachers "often will tolerate student cross discussion, but they do not encourage it." (Lemke, 1990, p. 56) This statement is not true of Hurston class. Instead, she designs her teaching to nurture these moments.
Hurston's use of discussions reflect her goal of nurturing critical thought in her students, her emphasis of the procedures of science, and her reluctance to be the "class authority" on a topic. Loose triadic dialogues allow students to quickly suggest answers and remove Hurston as the focus of the classroom. The prominence of student cross discussion reflects the same tendency toward a student centered/controlled approach to dealing with course material.

Types of discussion questions

The most frequent type of question asked by Hurston during discussions was open-ended questions which could have many correct answers. Some examples of Hurston's questions include:

What does the first article tell you about how scientists work? (F 40)
What does paleontology tell us about science? (F 61)
What evidence is used for classifying organisms? What about DNA? (F 96)
Should we institute a genetic screening program at our hospital? (F 359)
If I want to know how many meal worms I have in this pan, how do I find out? (F 312)

The reliance on open-ended questions differentiates Hurston's class from many other science classrooms where students are required to recite definitions and factual information. Like her reliance on loose triadic dialogues, the use of this questioning strategy also allows Hurston's students a greater control of classroom material. These questions also allow students a greater freedom to use reasoning strategies instead of rote learning strategies in the formation of their answers. However, Smith et al. (1993) describe open-ended questions as improbable vehicles for eliciting conceptual change. These authors argue that open-ended questions do not provide an opportunity for students to contrast their alternative conceptions with a more scientifically accurate counterpart.
Discussion participants

Discussions in Hurston's class had a core of diligent participants. Four of the junior boys, Calvin, Philip, Bob, and Raistlin, could always be relied upon to participate in a discussion. Two additional boys, Brian and Jesus, would volunteer information if the correct answer was not immediately forthcoming or if the discussion began to grow tiresome for the rest of the class. These six boys carried the bulk of all class-wide discussions. If the topic was particularly interesting, another group would offer responses or ask additional questions. This small group included junior and senior boys and girls. While discussion were active in Hurston's class, not all students participated in the conversations. However, most students appeared to be engaged in the material as it was discussed; they turned their heads to watch the speaker and occasionally nodding in approval.

During a sampling of 18 different class discussions, 68% of the total class comments were offered by boys, and 3% of the total class comments were offered by girls. These comments took the form of answers or questions offered in whole class discussions. These figures correspond to my preliminary assessment that the boys, particularly the juniors, were much more active in whole class discussions. The differential participation becomes more striking when one considers that there were more girls in the class than boys. When I asked Tyler, a senior girl, about my observations, she commented:

SD: I've noticed that typically girls just don't talk a lot in [Ms. Hurston's class].

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2 My analysis of the effects of gender in the classroom is both superficial and brief. This state is regrettable in light of the pronounced effects gender had in classroom participation. After my initial observations, data collection, and interviews focusing on this topic, however, it became obvious that I was ill-equipped to tease out the meaning classroom participation, student power structures, and gender relations had for my participants. Therefore, I chose to report my initial findings while acknowledging that the gender of my participants played a role in learning I have not yet come to understand.
Tyler: Uh, uh. [Yes] It's cause the guys overpower everybody in that class.
SD: Is that really what you think?
Tyler: Yes. Because they don't give you a chance. I've, I've, I used to want to say a lot of stuff. And I would start saying and every time one of those guys would just blurt out
SD: Uh, uh. [Yes]
Tyler: and I just give up. I don't talk anymore. (C 187)

Tyler’s comments should be compared to comments made by Brian (a junior boy) and Stephanie (a senior girl). Both of these students had noticed that most of the questions were answered by a nucleus of boys, but they explained that this differential participation had to do more with the different personalities of the class members than any action of gender. Stephanie went on to explain that she will offer answers when she has something "new" to offer to the class. Other than this, however, she will remain quiet in all of her classes.

Differences in class participation between genders has been researched by many science educators. I was unable to investigate the hypothesis offered by Brian and Stephanie that students talked more or less frequently because of their personalities and not because of their genders. However, I did attend an English class taken by many of these same students, to see if the differential participation was due more to the subject than some other factor. The same trend held true in English; more boys volunteered information than girls. Based on the stable cross discipline results, the differential participation may be due more to general cultural influences than the action of a subject area.

Linn (1987) suggests that many aspects of the gender differences seen in science classes are due to the varied experiences of girls and boys both in and out of the science classroom. She explains that many girls have fewer experiences dealing with science-related topics out of school, and this differential experience accounts for the acceleration of boys in science. However, during my observations it became obvious that many girls knew the correct answers during whole class discussions, but
chose not to give voice to their knowledge. What is at issue is not a difference in the declarative knowledge of boys and girls, but a difference in their willingness to participate in whole group activities. It is here that past experiences may play a role in shaping the discussion behaviors of girls.

**Laboratories**

An analysis of the class reveals that it is heavily laboratory oriented. During the year, Hurston used 47 laboratories in her class. For the purposes of this study, a biological laboratory exercise is defined as an opportunity for experimentation and observations of some aspect of living organisms or practice of a experimental technique. (A list of the laboratories can be found in section 1 of Appendix D.) Hurston selected the laboratories based on the "extended discretion" approach (Leonard, 1980). Using this approach, the laboratories assigned early in the school year have pre-established procedures. Laboratories assigned later require the students to make more and more decisions in the structure of the laboratory. Hurston's goal was to have the students become able to plan and carry out their own laboratory investigations. She used the extended discretion approach as a means of "getting way from the cook-book lab. You give them less and less guidance, and they have to figure things out for themselves." (P 2)

Virtually all of these laboratory exercises were completed by the students in small groups during class hours. However, during the unit on animal behavior, three of the laboratories were completed by individual students after school hours, and another exercise was completed by the students a field trip to a local zoo. Only three units were not accompanied by laboratories; these included units on dinosaurs, evolution, and animal rights. But it must be remembered that these three units only accounted for only 26 of the total 143 instructional days.

The typical laboratory exercise would begin with the students being assigned to read the laboratory instructions the night before the exercise. The next day there would
be a short teacher exposition/triadic dialogue which would further explain the laboratory procedures. Afterwards, the students would divide into small groups of three to four members. The small groups, selected by the students, typically consisted of students of both genders, and the group members remained relatively constant throughout the school year. During the laboratory, Hurston and Joe Ellen remained available for students’ questions. Laboratory questions were predominately of a procedural nature as the students attempted to carry out the exercise. Students were required to turn in a set of questions or a laboratory report completed individually at the beginning of the next class day. Afterwards, the exercise would be discussed in the form of a loose triadic dialogue.

Hurston’s reliance on laboratories as a teaching method is congruent with her course goals of developing (a) a sound understanding of the nature of science, (b) the ability to think critically about methods and findings of science, and (c) a familiarity with common laboratory techniques. Hurston also describes the laboratory experience as an ideal method in capturing students’ interest in the practice of biology.

**Videos and Associated Media**

Hurston’s teaching during several units was dependent on the use of videos and other audio-visual media. Hurston used 20 audio-visual presentations as the main lesson activities throughout the school year. (A list of the audio-visual presentation can be found in section 3 of Appendix D.)

Typically the audio-visual presentation would be preceded by a short teacher monologue. Often, Hurston would stop the presentation to ask the whole class a question. Hurston expected students to pay attention during these presentations. For example, if she found a particular student’s attention to be wavering, she would lightly touch the student on the shoulder or whisper in her/his ear. The following day the video would be discussed in a whole class setting. On three occasions, the students were asked to write a short essay related to the contents of a video presentation.
Several units were structured heavily around audio-visual activities. These units included dinosaurs, animal behavior, animal rights, and evolution. Hurston found videos to be an effective means of presenting a great deal of very current information to her students. She explained that students can often learn a great deal from such presentations as long as appropriate means are selected to ensure their attention. It is her opinion that this method has the additional advantage of capturing students' attention in a generation that is heavily influenced by the media.

Readings

Because there was not a traditional text used in Hurston's course, much of the material was presented in the form of laboratory exercises, audio-visual presentations, and student readings. Most the 18 articles the students were assigned to read were taken from scientific publications designed for the public, such as Discover. Other articles were taken from science teaching journals, such as The Science Teacher, and selected essays on natural history, such as Natural Acts. A small number of articles were selected from newspapers and tabloids. (For a list of the readings, see section 2 in Appendix D.)

Most articles were assigned to be read as homework. The following day Hurston would lead a whole class discussion of the article or the students would be asked to respond to the topic in the form of a journal entry. Other class periods consisted of students selecting articles from publications such as National Geographic, Discover, and Omni. The students were to read articles they found interesting and to give a summary of these to the entire class. In this way, Hurston found students could be exposed both to many different types of current scientific research and their co-worker's interest in such topics. In other cases, Hurston would read a particularly compelling article aloud to the class. She took this approach with some of the passages from Jane Goodall's book, Though a Window, and a short story by Isaac Asimov, "The Winnowing." Almost all readings were discussed in a whole group setting. These
discussions often became detailed and combative, with students arguing different
points made by the authors.

Hurston relied upon these outside readings because, unlike a text-book, they
provided her the freedom to select topics not previously addressed in the students' prior
biology classes. This freedom allowed her to select interesting topics and to address
these topics with articles that she had found to be personally useful. Hurston also
selected articles based upon their degree of difficulty and sophistication. Student
readings were selected to achieve the goals of understanding the science content,
enhancing interest, understanding the nature of scientific processes, and perfecting
critical reading skills.

Student Journals

Ten student journal writing assignments were made during the school year.
(For a list of these assignments, see section 4 in Appendix D.) Each assignments was
designed to aid students' skills in written communication. Hurston explained that
journal entries require that the students go beyond simple rote learning to critically
analyze or apply scientific theories. Additionally, journal entries require students to
integrate information from several different sources.

Additional Activities

After Christmas break, the students were required to turn in a report of a
science fiction book. In the report, the students were expected to summarize the book
and analyze the science in the book in terms of its accuracy, plausibility, and scientific
authenticity. Students also were to describe the social or moral implications of the
book.

Hurston had several ideas in mind as she assigned the book report. She hoped
to spark some students' interest in science through their pre-established love of reading.
She wanted to provide an opportunity for students to integrate and apply their
knowledge of science in an unusual setting. Most importantly, Hurston hoped her
students would see the connection science has to other disciplines, such as English, politics, mathematics, and economics. This teaching practice thus satisfied one of her course goals.

In relation to the goal of recognizing the relationship of science to other aspects of students' lives, Hurston placed a *Farside* cartoon on the overhead at the beginning of each day. While this cartoon served as an "attention getter" and provided a light-hearted topic with which to begin class, she also felt that these cartoons allowed student to begin to recognize "the science in common, ordinary, everyday things." (P 48)

**Assessment**

The students received many grades in Hurston's Biology II course, many more than they received in most of their other classes. Semester grades were determined from journal entries, laboratory reports, class presentations, laboratory and class participation, and examinations. There were only four examinations administered in this course. The first semester had an exam given after the first quarter of classes, an examination on the pig dissection, and a semester final examination. The second semester had only the final exam.

The examination questions reflect much of Hurston's teaching philosophy and goals. (See Appendix E for a summary of examination questions.) Hurston's felt that a student's performance on a test should not radically alter her/his course grade. Instead, the student's grade was mainly determined by the student's daily performance in class. Hurston's questions did not require students to respond with factual information; instead they required applications of known laboratory procedures, synthesis of theories learned during the course, and critical reflection on the content and methods of scientific inquiry. The sole exception to this trend was seen in the anatomy laboratory practical prepared by the student teacher.
Teaching Evolution

Hurston views evolution to be the major theoretical framework of biology. As such, the theory of evolution was a fundamental theme of her Biology II course. This prominence is reflected in her choice of instructional units for the course. The theory of evolution is the essential component of the instructional topics of dinosaurs and anthropology. Further, only two units, genetic techniques and microbiology, had no specific mention of evolution in their instruction. With the exception of these two units, instruction in evolution was integral to all course instruction. (See Appendix F for specific details of the instruction in evolution.)

Evolution was taught as a distinct teaching unit at the beginning of the second semester. This unit was taught intermittently during 10 days, and a large portion of this time included instruction into the various forms of evidence which supports evolutionary theory as well as the patterns of evolution seen in the natural world. The forms of evidence stressed by Hurston included microfossils, fossils, and the explanation of physical processes as the source of recurring, natural patterns.

As mentioned previously, other units relied heavily on evolution as their theoretical basis or in their application. These instructional units included dinosaurs, animal behavior, and anthropology. The theory of evolution is inherent to the study of dinosaurs. The dinosaur unit required the students to analyze the various theories of dinosaur extinction, as well as the proposed relationships of dinosaurs with the reptiles and birds. Likewise, evolution is inherent in the study of anthropology as human relationships with other primates are investigated. The evolutionary relationship of humans to other primates was also investigated by the students in the unit on animal behavior. It should be pointed out that this emphasis is not necessarily implicit in the study of ethology. Instead, Hurston's selection of primates as her class' main study group made evolution a fundamental aspect of this instructional unit as students sought to apply the results of research.
As suggested by the National Research Council (1990), instruction in evolution was interwoven throughout the course. Aside from the formal unit, there were 36 instructional episodes in evolution. An instructional episode in evolution is used to refer to any instructional event which focused on or referred to some aspect of evolutionary theory. The Biology II course had a total of 51 instructional episodes in evolution. Of these 51, 36 episodes were designed specifically to address some aspect of evolutionary theory. The remaining episodes simply mentioned some aspect of evolutionary theory during the instruction of another biological topic. Figure 3 represents the position of each instructional episode of evolution during the semester. (See Appendix F for a detailed chart of each instructional episode.)

Aspects of Evolutionary Theory Addressed

Figure 4 represents the most common aspects of evolutionary theory addressed in the course. As shown in Figure 4, many segments of the broad theory of evolution were the subject of instruction, including: (a) historical aspects, (b) evidence for evolution, (c) evolutionary relationships, (d) patterns of evolution, and (e) aspects of evolutionary explanations. An analysis of the instructional topics revealed that no single segment stands out as the most prominent focus of instruction.

Hurston's instructional approach to evolution is of particular interest. As seen in Appendix F, the mechanisms of evolution were not emphasized by Hurston. Traditional biology classes stress knowledge of mechanisms and omit other aspects of evolutionary theory. Instead, Hurston taught evolution much like she taught the rest of her class by stressing knowledge about the theory instead of the actual mechanism of the theory. Hurston's course emphasized the (a) application of evolutionary theory to diverse biological realms (including an emphasis on humans as evolving organisms), (b) the plethora of evidence found in the natural world for evolution, and
<table>
<thead>
<tr>
<th>Historical aspects of present evolutionary theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darwin</td>
</tr>
<tr>
<td>Galapagos</td>
</tr>
<tr>
<td>Lamarck</td>
</tr>
</tbody>
</table>

| Scientific evidence for evolution                |
| Fossil evidence                                  |
| Geological changes                               |
| Natural patterns                                 |

| Processes of evolution                           |
| Mechanisms                                       |
| Natural selection                               |
| Genetic Drift                                    |
| Sexual selection                                 |
| Rate of evolution                                |
| Gradualism                                       |
| Punctuated equilibrium                           |
| Saltation                                        |

| Patterns of evolution                            |
| Adaptive radiation                               |
| Convergence                                      |
| Divergence                                       |
| Human (primate) evolution                        |

| Evolutionary relationships                       |
| Dinosaurs and reptiles                           |
| Dinosaurs and birds                              |
| Humans and other primates                        |
| Species concepts                                 |
| Taxonomy                                         |

| Aspects of evolutionary explanations             |
| Anthropomorphism                                 |
| How versus Why questions                        |
| Limits of scientific explanations               |
| Teleology                                        |

Figure 4
Aspects of evolutionary theory addressed in instruction
(c) the means through which evolutionary explanations (as well as all scientific theories) can be applied.

Hurston devoted only four instructional episodes toward an examination of evolutionary processes. Three of these episodes were discussions, and the fourth was a student reading of "Evolution since Darwin" (Rensberger, 1982). One of the three discussions centered on this article and occupied an entire class session.

Instructional Methods Used in Evolution Instruction

Table 5 shows the various instructional methods employed by Ms. Hurston in teaching evolution. Of interest here is the prominence of discussion as an instructional method. Evolution (emphasizing the mechanisms of evolutionary processes) is the sole topic in which Ms. Hurston devoted an entire class session to discussion. There were commonalities between the three instructional episodes in which evolutionary processes were addressed. Each was a triadic dialogue, in which Hurston asked very specific questions of her students and commented on their answers. As Smith et al. (1993) explain, a narrowly defined question is a more appropriate method for eliciting conceptual change. Through these dialogues, students are more likely to compare their conceptions with those of science than they would be in Hurston's loosely structured dialogues based on open-ended questions. The following is an example of the discussions held during the unit of evolution:

**Hurston:** Do we normally have nonrandom mating?
[No answer from the class]
**H:** In any population, not just humans? Any population, animals or whatever? Is there normally random mating?
**Joe:** Yes.
**H:** You think animals mate randomly?
**J:** Yes.
**H:** Then why do we have sexual dimorphism?
**J:** What's that?
**H:** Sexual dimorphism is when there is a different characteristic between male and female, and we have sexual selection on the basis of those characteristics.
**J:** Not many things do that.
H: Why do we have all brightly colored birds and big peacock tails and all this sort of things?
J: Reproduction.
P: Reproduction. Random mating?
J: Well, mammals don't do that.
P: Do what?
J: Have big feathers and all.
P: Ah, I see. How about the big antlers and all? (F 458)

The comparison of students' conceptions with scientific conceptions is a necessary condition for promoting conceptual change. It is significant that

Table 5
The number of instances in which instructional methods were used in teaching evolution

<table>
<thead>
<tr>
<th>Instructional Method</th>
<th>Number of Instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio-visual Presentation</td>
<td>6</td>
</tr>
<tr>
<td>Cartoon</td>
<td>2</td>
</tr>
<tr>
<td>Discussions</td>
<td>21</td>
</tr>
<tr>
<td>Examinations</td>
<td>3</td>
</tr>
<tr>
<td>Journal Entry</td>
<td>5</td>
</tr>
<tr>
<td>Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>Reading</td>
<td>6</td>
</tr>
<tr>
<td>Student Presentation</td>
<td>1</td>
</tr>
<tr>
<td>Worksheet/Questions</td>
<td>5</td>
</tr>
</tbody>
</table>

triadic dialogues allowing such comparisons were most prominent when the actual mechanisms of evolutionary change were addressed.

Other means through which the mechanisms of evolution were addressed was through student reading and a whole class discussion of a reading. Hurston assigned the Science 82 article entitled, "Evolution since Darwin," early in the second semester (Rensberger, 1982). In this article, Rensberger compares the basic tenants with Darwin's theory of evolution through natural selection to the theories currently employed by science. He also provides a very general explanation for the new
synthesis created by the linkage of genetics and evolutionary theory. This article is brief and written in very informal terms. However, in the four pages, the author provides a historical view of the changes of evolutionary theory, discusses current controversies that exist within this framework, and describes various theories of the scientists working within this framework.

Four days after the reading assignment, the whole class discussed this article. Discussion took the form of a structured triadic dialogue. Through her questioning, Hurston emphasized both the mechanisms described in the article and the newer theories that exist within the theoretical framework of evolution. This discussion included the mechanisms of natural selection and genetic isolation in their relation to speciation. This discussion also included the broader evolutionary theories of gradualism, saltation, and punctuated equilibrium. The new synthesis was also explained by the students under the direction of Hurston's questions.

(For more detailed information on the instructional methods used for instruction in evolution, see Appendixes D and F.)

Student Evaluation

As Tobias (1990) points out, students often interpret the material emphasized on an examination to be the material actually valued by the instructor. When Hurston's examinations are reviewed, it becomes evident that Hurston understands evolution to be the major theoretical basis for biology. On each of the three major examinations, at least one question dealt with some aspect of evolution. (One question typically carried 25% of the grade.) (See Appendix E for a list of the exam questions.)

Summary—"Thinking Skills in the Context of Biology"

In our casual discussions, Hurston often described a difference she perceives between memorizing science and learning science. She explained that, "if you cannot apply information, then it is useless." (P 65) She explains that her course is designed to:
Hurston: teach them how to look at things and think about them. I stress thinking skills in the context of biology. Hopefully at the end of this course they will be interested enough in biology to want to continue learning about the content of biology. And ah, they will know how to do that on their own if necessary. So that, whatever comes up that involves a biology issue, they will be literate enough to understand, appreciate, make commitments or choices. (P 19)

Hurston's course stressed what Dushl (1990) refers to as "knowledge about science"—that is "knowledge of both why science believes what it does and how science has come to think that way—instead of "scientific knowledge"—that is the factual information which results from the process of science (p.10). Looking over Hurston's course, one might argue that often the knowledge about science was stressed to the partial exclusion of scientific knowledge. To this, Hurston has argued that this course is designed to be a capstone course, one which allows students an opportunity to learn the procedural knowledge of science. Knowledge of the scientific procedures allows them the opportunities to apply their declarative knowledge of the discipline.

While the strong laboratory component demonstrated in Hurston's course might invite the label of the course as a "hands-on" approach, I would use Duschl's term of "minds-on." Hurston's Biology II course allowed her students to construct the procedural knowledge the students need to fully understand the discipline of biology.

Toward the end of the school year, a senior girl gave this assessment of the course:

Meredith: I've enjoyed it [the course], and I think the things we've done were will certainly benefit ah help me
SD: Uh, uh. [Yes]
M: in the future. You know it's not, it's not like some classes where you forget everything you've learned you know?
SD: Okay, so ahm you don't think that's gonna happen with this?
M: Na, ah. [No]
SD: I wonder why?
M: I just, I think it's the way, ah the way she teaches. A lot, you know that you don't, you don't do ah writing down definitions from the book and memorize them and spit them back out on a test.
SD: Uh, uh. [Yes]
M: It's not that kind of course. (A 302)

As suggested by Lemke (1990), Hurston structured her class to provide ample opportunity for students to talk and write about science. Although she used triadic
dialogues frequently, in her class these were informal affairs requiring student participation and allowing for more student control over the material being presented. Her course included many laboratory experiences for the students. Like her discussions, the laboratory experiences were designed, not to transmit large amounts of information, but to foster student questioning of course material.

As reflected by her instructional methods, Hurston informally recognizes learning to be a social process, and her classes are designed to nurture student interaction and participation in the language and processes of science. A close examination of her instructional methods reveals that many do not conform to the description of conceptual change teaching strategies as described by Smith et al. (1993). Hurston depended heavily upon open-ended questions which could have many correct answers during the initiation of class discussions. She also fostered student debate in her classrooms. Smith et al. (1993) suggest that such questioning strategies do not promote conceptual change because students are not required to compare their prior conceptions with those of science.

In her effort to elicit student participation and to foster students' interest, Hurston stressed participation in scientific conversations over the declarative knowledge of science. Therefore, it would be inaccurate to label Hurston's teaching as based on the theoretical base of conceptual change. Hurston's teaching stressed the application of biological theories. In her class, students were expected to apply theories they had studied during the present and previous classes. While students were not drilled on the content of theories, they were expected to apply these theories to diverse biological phenomena. The application of theories for explanation and prediction is a necessary component of the development of a greater scientific understanding (Anderson & Roth, 1989).

If Hurston's class did not explicitly stress the comparison of students' theories with those of science, her teaching methods did provide a climate in which students felt
comfortable in voicing and exploring their personal understandings of biological phenomena. Once again, it becomes evident that Hurston’s class is designed around promoting the social construction of knowledge. Like the conceptual change programs designed by science educators, Hurston understands learning to occur in an open, interactive classroom community.

In teaching evolution, as in her course as a whole, Hurston’s teaching required students to (a) apply aspects of evolutionary theory, (b) compare and comment on the merits of various theories within the framework of evolution, and (c) reflect upon the links of evolutionary theory to other aspects of biology. Hurston did not stress the mechanisms of evolution as much as she did their application. Students were expected to discuss implications of evolutionary theory in whole group discussions, small group work, and written reports. This socially based approach answers Settlage’s (1992) call for application of instructional conversations in the instruction of evolution. While she did not use conceptual change teaching techniques when teaching evolution, the instructional conversations which occurred in classroom discussions were necessary tools in promoting the conceptual growth of her students.
CHAPTER 6

DESCRIPTION OF CONCEPTUAL CHANGE IN EVOLUTION

Introduction

In Chapter 6, the final results and discussion chapter, the patterns of conceptual change are reported. This description proceeds in an individual fashion as the conceptual change of the class and each of the four interview participants is independently detailed. Data for each of these five sources are reported, and individual trends are tied into the literature. Not until the summary for this chapter are cross-participant patterns outlined and discussed in light of current conceptual change literature and the teaching practices of the participating teacher. This comparison may be the most interesting to the reader as the more salient aspects of the findings are discussed. The summary section begins on page 272 and is continued in the conclusions and implications chapter (Chapter 7).

The Class

The conceptions of members of the entire class are reported as a reference for the results of the four interview participants; they provide some insight as to the normal patterns of conceptual change of students who were not interviewed on a semi-weekly basis. Because the conceptual change of the class is not a major research focus, these data are reported briefly, and their implications for teaching are fully discussed at the end of this chapter.

The Use of Scientific Conceptions for Evolution

The pre- and posttest conceptions of all of the students were measured using the Bishop and Anderson exam (1985). When the results of this instrument are scored using the criteria developed by Bishop and Anderson (1985), the number of students who hold a scientific conception are determined. Three conceptual issues central to an understanding of the process of evolution by natural selection are examined in this scoring method. These issues include:
(a) the origin and survival of new traits,
(b) the role of variation within the population, and
(c) the nature of evolutionary changes within a population.

Of the three conceptual issues, fewer students used the scientific conception for the origin of variation than the other two conceptual issues. (Table 6 is a comparison of the pre- and posttest findings.) In comparison to a study conducted on the neighboring university campus by Demastes et al. (in press), a greater percentage of students in Hurston's biology class used the scientific conception of mutations as the source of new variation upon entering a nonmajor's biology course than college students.

<table>
<thead>
<tr>
<th>Conceptual Issue</th>
<th>Pretest (N=22)</th>
<th>Posttest (N=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin and survival of new traits</td>
<td>14</td>
<td>43</td>
</tr>
<tr>
<td>Role of variation within the population</td>
<td>63</td>
<td>42</td>
</tr>
<tr>
<td>Nature of evolutionary change in a population</td>
<td>45</td>
<td>38</td>
</tr>
</tbody>
</table>

When the second and third conceptual issues are examined, a relatively high percentage of Hurston's students were found to use a scientific conception for these issues during pretesting. These figures are surprising when they are compared to similar figures from the Demastes et al. (in press) study where no more than 17% of the college students used a scientific conception for either conceptual issue. Bishop and Anderson (1990) report that no more than 31% of their students exhibited the use of any scientific conception for these three issues. These findings demonstrate that many students in Ms. Hurston's biology class had a sound understanding of one or more of these issues as they entered the class even though they did not understand all the central issues in how evolution is mechanized.
As Table 6 demonstrates, the early promise of these students was not retained upon posttesting. While there was a large gain in the number of students using a scientific conception for the origin of variation, the percentages decreased for the other two conceptual issues. Although each of these posttest figures is higher than those reported for the college students in Demastes et al. (in press), this study documents an overall declining percentage of students using a scientific conception for two of the conceptual issues. Such a declining percentage has not been reported in other similar studies.

Patterns of Conceptual Change

One of the drawbacks of using the Bishop and Anderson (1985) method of scoring is that only students' use of scientific conceptions is measured; it does not reflect their use of alternative conceptions for a conceptual issue. Because of this, many patterns of conceptual change which may be occurring are masked. In order to learn more from the pre- and posttest, a scoring method described by Demastes and Good (1993) was employed. In this method, students' conceptions are categorized and analogous pre- and posttest conceptions are compared so the pathway of conceptual change can be described. The scoring system documents the most prominently-used conceptions for three conceptual groups in a conceptual framework of evolution. (A conceptual group refers to all of the conceptions which refer to the same phenomenon.)

Students' Conceptual Frameworks

When the students' conceptions were categorized using the Demastes and Good (1993) scoring method, these conceptions were found to be very similar to those described in a variety of similar studies (Bishop & Anderson, 1990; Demastes & Good, 1993; Settlage, in press). Similar to Bishop's and Anderson's (1990) evolutionary issues, the three conceptual groups described in this study included (a) the species concept, (b) the unit of evolutionary change, and (c) the origin of variation.
Comparisons of the students holding conceptions in each of these groups are shown in Figures 5, 6, and 7.

Conceptual group 1-species concept

The most frequently used conception in this group was the typological species concept. A large percentage of the students failed to recognize the variation that exists within a population of organisms. Instead, these students understood a species to be a large group of organisms which have similar traits (the typological species concept):

**Jean**: [In reference to the evolution of speed in cheetahs] As their prey became more specialized, all of the cheetahs may have needed to run faster to catch food or escape. (Pretest #7)

**Tom Ian**: [In reference to the evolution of blindness in cave salamanders] Because of their living in caves with no light their eyes were not necessary and they gradually stopped working in all of the salamanders. (Pretest #8)

This conception becomes more clearly defined when one looks at its scientific counterpart, the variable species concept:

**Bob**: [In reference to the evolution of speed in cheetahs] There were probably a few cheetahs which could run extremely faster than the others. These faster ones could catch prey easier than the others, therefore allowing them to survive. The slower ones would die off leaving only the fast ones to breed. (Pretest #7)

(For a comparison of the pre- and posttest percentages of students holding conceptions in this area, see figure 5.)

The trend for students to use the alternative conception of a typological species concept has been documented by other researchers (Bishop & Anderson, 1990; Halldén, 1988). Its prominence, both in this study and the literature, indicates that this is a fundamental conception that prevents construction of a scientific conception of natural selection. As shown in Figure 5, more students used the typological species concept during posttesting. However, many students did use the scientific understanding of the variable species concept.
Conceptual group 2-unit of evolutionary change

The unit of evolutionary change contains the second major alternative conception seen in the students, the conception that evolution of a trait occurs in all members of a population. This conception is closely related to the typological species concept. Students using the typological species concept to discuss evolution are constrained into explaining that all members of the homogeneous population evolve. Because of the close relation of these two concepts, the same data sources were used to identify the conception that all members of a population evolve and the typological species concept.

**Susan:** [In reference to the evolution of speed in cheetahs] As time went on the cheetahs began to have shorter muscles [sic] in their legs which made them better runners. Also the land may have changed and they could have better conditions to run in. (Pretest #7)

**Stephanie:** [In reference to the evolution of speed in cheetahs] Gradually the cheetahs developed stronger legs. Having food as an
incentive, the cheetahs ran faster and gained stronger muscles in their legs that were passed on to the offspring. (Pretest #7)

Two other conceptions were identified that are related to the one described above. The first of these is the idea that evolution is the change of a trait found in one individual. The population or species is not considered by students using this conception. This was not a common conception in the group of students and the number of students using this conception dropped noticeably during posttesting:

![Graph showing pre- and posttest conceptions for conceptual group 2-unit of evolutionary change.]

Note. The percentages do not always equal 100 because alternative conceptions that were not held by a large percentage of the class were not reported.

**Calvin:** In reference to the evolution of blindness in cave salamanders] Since it was dark, there was no need for sight, so he lost this sight and probably developed more enhanced smell and hearing. (Pretest #8)

The conception of evolution as a change within all members of a population and the failure to consider the population as involved in evolution can be contrasted with the scientific conception for this conceptual group. The scientific conception for the unit of evolutionary change explains that evolution changes the percentage of the members of a population with a specific characteristic:
Amanda: [In reference to the evolution of speed in cheetahs] As the population of cheetahs grew the ones who ran the fastest got the food. So eventually this trait evolved. (Pretest #7)

Brian: [In reference to the evolution of speed in cheetahs] The slower cheetahs would die because of starvation and leave only the fastest. This would happen generation after generation until the very fastest could run 60 mph and his offspring would be the surviving species. (Pretest #7)

The use of this scientific conception was much more common in this study than in Demastes and Good (1993). However, there was not a dramatic increase in the use of this conception during posttesting. (For a comparison of the pre- and posttest percentages of students holding conceptions in this area, see Figure 6.)

Conceptual group 3-origin of variation

The third most prominent alternative conception used during pretests was need as the origin of variation.

Meredith: [In reference to the evolution of speed in cheetahs] Obviously, cheetahs needed to run faster. Perhaps it was necessary for them to catch their prey and to survive. This occurred because of a need for adaptation. (Pretest #7)

Meredith: [In reference to the evolution of blindness in cave salamanders] Cave salamanders, living in a dark environment, did not need to see. Over the years they evolved to loose [sic] this unnecessary function. (Pretest #8)

The prominent use of need in students' conceptual frameworks for evolution has been documented by several other researchers (Clough & Wood-Robinson, 1985b; Deadman & Kelly, 1978; Settlage, in press). The use of need was particularly resistant to instruction in our students, evidenced by some students' incorporation of the explanation of mutation into their pre-existing conception of need:

Juanita: [In reference to the evolution of webbed feet in ducks] The mutation was made because they [the ducks] need to swim in water. (Pretest #4)

Another conception of the source of variation is found in the students who used anthropomorphic answers, explaining that variation is produced through a conscious
decision by the organism. Several students reported that mosquitoes had to "learn" to become resistant to DDT. Tyler explains her answer:

SD: I'm just trying to figure out what you mean by learned. You know.

Sometimes

Tyler: They [the mosquitoes] figured out what, what was going to kill them I guess.

SD: Okay.

T: And what they had to do to not die.

SD: Okay.

T: What they had to do for themselves.

SD: Do you think a lot of animals do that?

T: I think probably so. [C 19]

The use of anthropomorphism to explain the source of variation is closely related to the need conception. Its use simply places another step in the sequence of the need explanation. Many researchers in this area have identified anthropomorphism in students' answers (Clough & Wood-Robinson, 1985b). Brumby (1984) and Halldén (1988) indicate that anthropomorphism may be an artifact of habits used in written and verbal communication on this topic. Tyler's comments demonstrate that the use of learn is not always an artifact of communication. She understood insects to be able to consciously modify their behaviors. She was not alone in this conception. At one point during the school year, Philip and Calvin came back in the room after class to ask Ms. Hurston if ptarmigan’s "could decide to change their feathers" from the summer brown to the winter white. A segment of students understood organisms to be able to consciously change physiological processes. Many students did undergo conceptual change away from this conception, but its use was retained by a number of students.

The use/disuse explanation contrasts with the conceptions of need and conscious decisions:

Tyler: [In reference to the evolution of blindness in cave salamanders]

From living in caves the salamanders used very little of their sight. From not using their eyes they became nonfunctional. This trait was passed down to other generations. (Pretest #8)

The use/disuse explanation may be an artifact of the use of commonplace expressions to solve problems, but its use is closely related to the conception of need
(or lack of need) as the source for new variation. Lamarckian explanations have been described by other researchers as a prominent aspect of students' explanations of evolution (Brumby, 1984; Jiménez, 1992). Few students used this explanation during either pre- or posttesting.

Each of the three alternative conceptions for the production of variation can be compared to the scientific conception of mutation. The use of mutation is fundamentally opposed to the prominent conception of need as the factor in producing variation. However, a small number of the students did use this scientific conception during the pretest:

Peggy Sue: [In reference to the evolution of speed in cheetahs] A mutation occurred in one cheetah and he had an advantage over others. He passed on this mutation, and finally it became prevalent. (Pretest #8)

In the comparison of the need and mutation conceptions, it should be noted that the use of mutation as the source of variation allows the student to separate the process of the production of variation from the process of natural selection. In contrast, the use of need as an explanation blends these two processes and prohibits the construction of a more complex, scientific conception of evolution. The conception of mutation as the source for variation demonstrated the greatest increase in student usage from pretest to posttest. This contrasts sharply with the findings of other researchers using this test instrument (Demastes et al., in press) However, in his work with high school students, Settlage (in press) also documents an increase in students' use of mutations as the origin of variation. But the gains described in his research were much more modest than those seen here. Work by Lawson and Thompson (1988) explains that students in high school are not prepared to understand mutation because it is such an abstract concept and most students are capable of only concrete reasoning patterns. However, the findings of this study demonstrate that the conception of mutation is accessible to high school students. (For a comparison of the pre- and posttest percentages of students holding conceptions in this area, see Figure 7.)
Pathways of Conceptual Change

Figure 8 shows the most prominent pathways of conceptual change experienced by the students in this study. (The conceptual change reported here is limited to the major conceptions identified in this study. Therefore, Figure 8 shows only the major pathways of conceptual change, but does not report all instances.) In order to interpret Figure 8, the direction of the arrows should be noted. For instance, for the Group 1 Species concept, two of the students that used the homogenous conception of the species during the pretest experienced conceptual change during the span of the study and used the variable species conception at the end of the study.

Even with the relatively low degree of conceptual change experienced by the students, some patterns emerge. Individual students experienced conceptual change (a) away from an alternative conception toward a scientific conception, (b) away from one alternative conception within a group of alternative conceptions to another, and (c)
Scientific conceptions | Alternative conceptions

Group 1. Species concept

The traits of species are variable | The traits of species are homogenous

Group 2. Unit of evolutionary change

A portion of the population changes | All individuals change

Group 3. Origin of variation

Mutation | Need

Note. The numbers indicate the number of students experiencing that pattern of conceptual change.

Indicates

Movement toward a scientific conception

Movement away from a scientific conception toward an alternative conception

Movement from one alternative conception to another

Figure 8
Pathways of conceptual change experienced by students within three conceptual groups for the theory of evolution
away from a scientific conception, toward an alternative conception for a group. These patterns of conceptual change are similar to those described for college students in a non-major biology course (Demastes & Good, 1993).

Some students holding each of the prominent alternative conceptions did experience conceptual change toward the scientific conception. Thus, for each of the groupings identified, a small group of students learned to use the scientifically accepted conception. However, none of the students holding the alternative conception of use/disuse as the origin of variation group moved toward the scientific conception. Instead, students using this conception experienced no conceptual change or moved toward another conception.

The second type of conceptual change, from one alternative conception to another, was the most common. Some students represented in all conceptual groups experienced this type of conceptual change. The third type of conceptual change, away from a scientific conception toward an alternative conception, was experienced by students in all conceptual groupings. This striking pattern of conceptual change has been documented in an earlier study (Demastes & Good, 1993) and will be discussed in the summary of this chapter.

Other Aspects of Students' Conceptual Frameworks

The description of conceptual frameworks and conceptual change deals only with students' conceptions of the process through which evolution operates. Another aspect of students' frameworks for this area is their acceptance of the validity of the theory. As students' acceptance of evolution is discussed, it is important to remember that there were 12 juniors in this class of 22 students, and each had successfully completed Ms. Hurston's Biology I course the previous year. Hurston describes her Biology I course as a thematic approach to biology with evolution as a central unifying theme. The seniors, however, had taken biology two years prior to this course and did not have Hurston as their teacher. The seniors could recall little of the material this
past course addressed, and not one of the five seniors I spoke with could recall the topic of evolution being addressed in any fashion.

One of the questions on both the pre- and posttest asked, "What is your opinion of the theory of evolution." The vast majority of the students wrote on their belief of the theory. Of the group describing their acceptance or belief, 92% of the juniors and 50% of the seniors expressed a belief in evolution at the outset of the course. At the end of the course, 91% of the juniors and 80% of the seniors expressed their belief in the theory. Simply the number of students responding with a discussion of belief to a question which asked about their opinion is important. This response signifies students' perceptions of evolution as being an area of intense personal conflicts for many people, as shown in this passage:

**Peggy Sue:** My opinion of evolution is basically undecided. I believe in God, but I do not know enough about the Bible to explain why. When I hear about people evolving from apes-the facts seem believable-so I do not know what to believe!! (Pretest #9)

Also, many more juniors expressed a belief in evolution than did seniors; however, it must be remembered that these students were a biased sample as they had recently completed a biology course based upon the topic of evolution and had elected to take another course from Hurston.

In response to the same question, "What is your personal opinion of the theory of evolution?" 32% of the students mentioned the issue of human evolution in their answers during the posttest. This percentage increased on the posttest to 52%. Clearly, for many of these students, human evolution is an important aspect of their acceptance of evolutionary theory.

Finally, regarding the same question, several students equated evolution with the initial creation of the universe/earth. In response to the same question, 14% cited problems with the validity of the "big bang" as a limitation of evolutionary theory. This number increased to 33% on the posttest. Just as Fisher (1992) suggests, students are unaware of the scientific boundaries of evolutionary theory.
Peggy Sue: I feel that it [evolution] has happened, but I don't believe in big bang or anything like that. (Pretest #9)

For many of these students, the over-application of biological evolution caused a degree of learner dissatisfaction with the theory.

Summary of Class Conceptual Framework

Many of the students entered this Biology II course using scientific conceptions of several aspects of evolution. In this regard, this is a much different student population than the college students described in earlier studies (Bishop & Anderson, 1990; Demastes et al., in press). But it should be remembered that the students of this class selected this course as an elective, and the great majority of these students were interested in professions closely related to biology or another natural science.

Of all three patterns of conceptual change documented for this class, the one which holds the greatest theoretical and methodological implications is the change away from a scientific conception. While the sample size was relatively small, a marked number of students underwent conceptual change away from the use of a scientific conception in each of the three conceptual groups. These findings support the other description of the students' conceptions provided by the Bishop and Anderson (1985) coding system. Many students in Hurston's class experienced conceptual change away from the scientifically acceptable explanation. While this movement has been documented in a similar study (Demastes & Good, 1993, conceptual change away from a scientific conception has not often been described. As a result, many researchers fail to consider such a pattern when designing data analysis methods. Such patterns indicate that conceptual change may be a much more piece-meal process than Posner et al. (1982) indicate. As suggested by Duschl and Gitomer (1991) and Nussbaum (1989), conceptual change may often be a fragmented process in which conceptions are selected and rejected for reasons other than a rational assessment of evidence.
The three most prominent conceptions held by students before instruction in the area of evolution were (a) populations of organisms are homogeneous (typological species concept), (b) change in a trait occurs in all individuals of a population, and (c) variation in a population is produced by need. The use of these conceptions changed slightly after instruction; most prominent was the substitution of mutation for need as the source of variation.

The Interview Participants

The conceptual change of the four interview participants will be described in this section. For each participant, this description will include:

(a) approaches the content area of biology,
(b) personal characteristics,
(c) conceptual ecology for evolution,
(d) conceptual framework for evolution at three major points in the year, and
(e) the changes in conceptual framework.

Of these five categories of description, only (c) and (d) require further explanation.

Conceptual Ecology

A conceptual ecology, as suggested by Toulmin (1972) and elaborated by Posner et al. (1982), includes the learner's fundamental organizing knowledge which controls and modifies further conceptual change. This fundamental knowledge can include conceptions, metaphysical beliefs, epistemological commitments, analogies, anomalies, and knowledge from areas other than that studied. Knowledge included in a learner's conceptual ecology is not easily modified. Aspects of the conceptual ecology bear strong resemblance to what Cobern (1993) refers to as a learner's world view. However, I will use the term conceptual ecology because of the theoretical basis of my study. The conceptual ecology is the aspect of knowledge most heavily influenced by the learner's culture. So it is here that the strongest theoretical ties are found between culture and what can be learned.
The portions of the learner's conceptual ecology that will be described include:

(a) religious orientation,

(b) acceptance or rejection of evolution,

(c) scientific orientation,

(d) scientific epistemology,

(e) view of the biological world.

These were selected because of their prominence during the course of the interviews and during data analysis. Data analysis indicated that these specific aspects of a learner's conceptual ecology can be very influential in the process of conceptual change for the topic of biological evolution.

The first two aspects of the learner's conceptual ecology listed above clearly involve belief systems, while the others may not. Belief is a very difficult area to study, as no one definition has enjoyed wide acceptance. As Pajares (1992) has commented, "It is difficult to know where knowledge has ended and belief began." For the purposes of this study, belief will be defined in the following manner. Belief and understanding are both forms of knowledge which may overlap. However, when these two types of knowledge differ, understanding includes knowledge which has an academic component, and belief includes knowledge which is taken on faith.

The learner's religious orientation reflects the degree to which the learner organizes her/his life around religious activities, understands the natural world through theism, or interprets personal and natural events through a religious lens. This aspect of the learner's conceptual ecology can be closely tied to the learner's acceptance or rejection of evolution. Acceptance is used here instead of belief so that both knowledge systems, belief and understanding, can be included. Students' conceptions will be classified in a system described by Nelson (1986). This system describes the conceptions of the origin of the earth and biological species as being expressions of (a) quick creationism (the earth and all species were created by God a few thousand years
ago), (b) progressive creationism (lineages have undergone subtle changes after being placed on the old earth), (c) gradual creationism (evolution is God's means of creating species on an old earth), (d) non-theistic evolution (the issue of God and religion should not be included within the limits of scientific discussions), and (e) atheistic evolution (there was no God involved in the creation of the universe).

Another portion of students' conceptual ecology includes learners' orientation toward science. This reflects the degree to which the learner organizes her/his life around scientific activities, understands the natural world through physical and material causation, or interprets personal and natural events through a scientific lens (Cobern, 1993). The learner's scientific orientation is also very closely tied to the learner's acceptance or rejection of evolution.

Tied to the learner's scientific orientation is the issue of her/his scientific epistemology. How does the student view the nature of scientific knowledge? Does this view (i.e., realist, relativist, pragmatist) change with the type of knowledge considered? What does the student recognize as the boundaries of scientific knowledge? How does scientific knowledge intersect with their other means of understanding? And more specifically, how does the student view the applications of biological knowledge?

The final aspect of the student's conceptual ecology considered is her/his view of the biological world. Does the student view nature as fundamentally competitive or harmonious?

Framework for Participants' Conceptions

There are many conceptions tied into any conceptual framework, and this situation is magnified for evolution. The theory of evolution is both internally complex and interconnected with the learner's belief systems. In an effort to systematize the description of conceptual frameworks, the categories of conceptions that surfaced in the study are displayed on Figure 9. (As
A template for the summary of participants' conceptual framework for evolution mentioned in Chapter 3, these categories were derived from the participants' interview data and were not pre-established at the outset of the study. These categories contain both instances of academic knowledge and belief. The descriptions on these figures are brief and are provided for the purpose of comparison within each participant over time and for comparison between each of the participants.

**Figure 9**

Brian: Biologist as Scientific Theorist

Brian was the only male interview participant and the only junior. Brian was not one of my original choices for interview participants because he demonstrated a reasonably coherent and scientifically accurate conceptual framework for the process of evolution at the outset of the course. But after several weeks of effort, it became clear that he would be the only male in the class who could fully participate. However, after the interviews began, my reservations dissipated. It soon became clear that not only did Brian not fully understand all aspects of the process of evolutionary theory, he was also very different from my other participants. I came to value the differences between my participants as a means of more fully understanding the process of conceptual change.
Brian was a quiet boy who continually had to push his long hair from his eyes as he spoke. Each week I had to "draw" him out in order to gain his full participation in the interviews. But, his shy demeanor did not signify a lack of engagement. Several times during the interviews Brian would draw on our past conversations in order to answer a question I asked. Often, he would return to questions asked 30 minutes earlier and rephrase his answers. As he "warmed up" to a topic of discussion, he would push his hair back more frequently and talk in a very animated fashion. Based on these behaviors, I felt I had Brian's full engagement during our interviews. The behavior was similar in class. While not talkative, he would volunteer answers only if he felt the answer "was not too obvious" and if no one else had previously offered the answer. Although he seldom spoke in class, many students would ask for his help while studying for an exam.

The most helpful description of Brian's approach biology is as a scientific theorist. Brian searched for an overview of what was being studied soon after he constructed an understanding of how the process worked. An example of Brian's frequent use of theories is seen in this discussion of the exam taken at the end of the year:

B: [Reading] What's your personal opinion of the theory of evolution? You mean, do I like it or?
SD: Ah, an opinion could be virtually anything. Do you think it's useful? Do you like it? Ahm, does it have problems?
B: Ahm, it's not fully understood.
SD: Uh, uh. (Yes)
B: But we know it happens. Pretty much. Some people still say is doesn't, didn't, but.
SD: Uh, uh. (Yes)
B: Most people think that it happened. Ahm, there are a lot of good ideas out there. Like people have all these theories.
SD: Uh, uh. (Yes)
B: That go into the theory of evolution. But nobody knows exactly what happens every time something changed. You know?
SD: Uh, uh. (Yes)
B: But ahm, Gould and Eldredge.
SD: Right.
B: Could explain maybe half of evolutionary changes. And then like, what's the latest thing? One of the articles related to the theory.
SD: Ah the Gia theory?
B: I mean that could explain the unicellular evolution.
SD: Yeah.
B: Or most of it. I mean because it could also be part of Gould's and Eldredge's theory.
SD: Uh, uh. (Yes)
B: Because that didn't really explain that much. They just explained how one organism goes to another one. Not how two could combine.
(...) So it's not fully understood. Nobody knows exactly what happened every time. But I mean we have a pretty good idea.
SD: Uh, uh. (Yes) (B 201-203)

In our discussions and his infrequent class comments, Brian seemed to enjoy talking and thinking about biology on a theoretical level. He often discussed the merits of various scientific theories, and in more unstructured interviews his comments would continually come back to an analysis of theories. He explained that he liked biology "because it lets you think." (B 43)

Brian's approach to biology, and more specifically, evolution, was to try to understand the broad processes. This approach may have been aided by his substantial knowledge of the working of the processes of each theory. As demonstrated above, Brian would examine, modify, and replace theories in an effort to explain broad natural patterns. He searched for answers to large-scale questions. This approach is not surprising when Brian's background is considered. His favorite subject was mathematics, and he also enjoyed a university computer programming course. For two consecutive years, a mathematics teacher has allowed Brian to work through a textbook at his own pace, since he found the class too slow and uninteresting. During the past four summers, Brian attended a university course designed to continue the interest of students gifted in science and mathematics. Brian explained, "I'm happiest solving an equation or plugging in numbers to a program." He elected to take Biology II only because Ms. Hurston "gives you a chance to think" and it represented one of the few advanced science or mathematics courses at U High.

Out of school Brian studied Latin along with his brother. At the beginning of the year, Brian hoped to study civil engineering in college, because he wanted to build "large things." But this interest changed to architecture. During the study, Brian was
continually involved in some type of project, such as preparing a cat skeleton, teaching himself origami, or repairing his very old car. He loved puzzles and often would turn the illustrated portions upside down in order to make them more challenging.

This view of Brian is somewhat misleading. His mother and Ms. Hurston explained that Brian worked with great effort only on topics or projects that interested him. Because he hated to write, he continually procrastinated in finishing English assignments. He liked group work, "because there's less for me to do." Ginger explained, "He's a genius, but he's so lazy." His grades were less than impressive in Hurston's class because he often failed to complete assignments. Of the four interview participants, Brian was the only one who was not anxious about school, "school is not one of the things that worries me." (B 148) His only regular pleasure reading included Discover and Popular Mechanics.

Brian's Conceptual Ecology

The most influential aspect of Brian's conceptual ecology was his distinct scientific orientation. Brian used traditional rational criteria in his understanding of science. In our discussion of the pseudoscientific topics, (Loch Ness Monster, ghosts, and aliens), Brian explained he didn't "buy into" these things. He accepted the occurrence of natural phenomena based on the plausibility of the event and not based on the opinions of authorities.

B: I can look at it and actually see what they say and logically if it can be done, or was done. I don't usually look into real formal texts or whatever. Like those journals or whatever?
SD: Uh, uh. (Yes)
B: I don't look for those but just usually I can look at it and actually see what they're saying and logically if it can be done. (B 59)

Brian viewed much of the world in this rational manner and looked for the coherence and causality of phenomenon. Rationality was a major criterion through which Brian understood natural phenomena and the events of his personal life.

B: Like my sister said, everything happens for a reason. (...) but I don't really believe that. I mean, if something happens, it's, it's because you either weren't ready for it or say I mean, there's not a plan ah
SD: Okay.
B: for the future. I mean, what happens happens and not for any reason. Well, for a reason, but not for anything, not for the future of anything. (B 71)

Brian's scientific orientation was in congruence with his realist epistemology of scientific knowledge. As shown in the quote from the previous section for Brian, to know something scientifically was to "know what happened every time." Brian viewed science as an attempt to provide answers that are different from those achieved in other disciplines. "Scientists look to prove something. Not just to give any answer, but to give the answer." (B 78) Brian viewed scientific knowledge as striving to describe reality. However, Brain was not a naive realist as described by Grosslight et al. (1991). He readily conceded that "There's always a possibility that science is wrong." (B 69) Brian described theories as an explanation that is well supported by the scientific community but can always be disproven.

B: Like I think it was Einstein, he said it, "It'd take a million experiments to prove my theory but only one to prove it wrong." We can't ever be a 100% sure [of a theory] but we can always be relatively certain. (B 76)

Brian, like many scientists, simultaneously understood science as an attempt to understand reality and realized that scientific theories are not a sure reflection of this reality, but valued theories none-the-less. He recognized that science needs both theories and facts to operate. But he used the conception that a "theory could become a fact if you collected enough, amount [sic] of information. To prove it, without a doubt." (B 81) When Brian explained that he believed in a theory, he actually meant that he viewed theories as very probable in occurrence. Facts, on the other hand, were true, authentic reflections of reality. This realist epistemology was also used in his approach to many other aspects of his life.

At one level of consideration, Brian recognized a distinct boundary between science and religion.

B: Science really talks about what happens and what causes it to happen. And philosophy is more for what reason it happens.
**SD:** And how about religion?

**B:** Religion? Uhm. That, it tries to answer, religion is a, a sort of philosophy but like it has, usually has, it usually points toward a greater being. (B 203)

However, at some levels, he saw science and religion as overlapping.

**B:** I was reading somewhere about, it was about astronomy and stuff and that how there were a lot of views about the nature of heavenly bodies....Like if you consider our solar system as needing to be order that, that if you look at it even close, it's not as ordered as it looks....This article was explaining how most of the theories do not support a Divine Being or Divine Plan. (B 203)

He viewed the intersection of the two ways of knowing as essential to scientific progress.

**B:** I mean if you kept them [science and religion] totally separate you wouldn't need, you wouldn't learn about either of 'em....I mean, if nobody, if everybody just believe in what was written down in the Bible....centuries ago, nobody would even try to think about that [evolution]. (B 204)

While Brian was not a religiously oriented person, he did not reject the existence of a "greater being." His personal life and knowledge was not interpreted through a religious framework. Along these lines, Brian did not interpret the writings of the Bible literally: "the Gospel according to John may be just a novel for what anybody knows." (B 201)

At the outset of the course, Brian ascribed to what Nelson (1986) refers to as a non-theistic evolution. For Brian, scientific truths were independent of religious assumptions. Additionally, scientific arguments for or against God were logically flawed. The existence of God is not something Brian would set out to prove. He accepted the plausibility and probability of evolution's operation in the natural world. Because of this acceptance and its connections to Brian's scientific orientation, the issue of understanding versus belief did not surface during the analysis of Brian's interview data. However, this issue will become important for the other interview participants.
Brian's Conceptual Framework for Evolution

Initial framework

Brian's scientific understanding of the process of evolution and his uses of the broader theories of evolution immediately serve to distinguish him from the other research participants.

**Mechanism.**

An understanding of the mechanism of evolutionary change is central to Brian's conceptual framework. When Brian was asked to concept map his "understanding of evolution" at the outset of the research, (CM-1, initial), his entire map consisted of an explanation for the mechanisms through which evolution operates. (See Appendix G for his concept maps.) This initial map closely resembled his map drawn one week later in response to the question "How does evolution work?" (CM-2, initial).

Knowledge of the process of evolution was also the most differentiated aspect of Brian's conceptual framework. The focusing on process is well suited to Brian's rational, scientific orientation. For Brian to understand a topic, it was very important for him to understand how it works.

Brian had a firm, foundational understanding of the neo-Darwinian explanation of evolution through natural selection. Major aspects of Brian's understanding of the process of evolution were: (a) mutation as the source of variation, (b) variable species concept, and (c) evolution as a change in the proportion of a population with a trait. While Brian used a scientific conception for these aspects of evolutionary change, there were some subtle differences between his conceptions and those of science.

Mutation as the source of variation is significant in Brian's understanding of process. In the two concepts maps for evolution, mutation is the second (CM-2, initial) and third (CM-1, initial) highest concept in the Brian's hierarchy. Brian's understanding of the various aspects of this conception is demonstrated by his comments during the sorting task:
B: You got, your all white. [Selects picture of white rabbits.]
SD: Uh, uh. (Yes)
B: And to get any change in color you have to have a change in your DNA. [Selects picture of DNA strand.]
SD: Okay. So, what is that?
B: This is ah, it's either some matter or some foreign...
SD: What's another name for that?
B: Chromosome, gene.
SD: Okay.
B: And then, this is your changed ones.
SD: Uh, uh. (Yes)
B: And then you have, do I use these all?
SD: Only if you want to. Use anything you want to.
B: Well, you have your introduction of the predator right here. [Selects picture of predominantly white, fewer brown group of rabbits with hawk.]
SD: Uh, uh. (Yes)
B: Which thrives on the white one.
SD: Why?
B: Because the brown ones are more camouflaged.
SD: Okay
B: I guess that's what it's supposed to mean with a brown background. [Selects picture of half white, half brown population of rabbits with hawk.] And then, as the predators get more and more white ones, the brown ones reproduce more.
SD: Uh, uh. (Yes)
B: So you get this one. And then finally, you get most brown ones and hardly any white ones. [Selects picture with predominantly brown population of rabbits with hawk.]
SD: Okay. Are you happy with that explanation? [He nods "Yes."] Pretty happy. Ahm, could any of those things happen at the same time? Or does it happen kinda in that progression, like you have it?
B: Well, these pretty much happen. This could happen, this part right here could happen hundreds of years before this.
SD: Okay. So the production of, of this change in the chromosomes
B: That, that couldn't be just been a freak thing.
SD: Uh, uh. (Yes)
B: That didn't completely die off.
SD: Uh, uh. (Yes)
B: And then it, it only came to their advantage when there was a predator that it gave a disadvantage to.
SD: So, two things are pretty separate in your mind? The production of the change and then the action on the change?
B: Right.
SD: Okay.
B: I mean it's not like this the hawk or whatever came and changed the DNA.
SD: Okay. Or the bunnies did it in response to the hawk?
B: Right.
SD: Could they have done it in response to the hawk?
B: No. (B 65-67)
This segment of interview demonstrates Brian's use of mutation as the source of variation for a population. It also demonstrates Brian's scientifically accurate conception of the separation of the production of variation from the action of natural selection. Bishop and Anderson (1990) explain this separation as being an essential step in constructing a scientific conception for evolution.

Brian's understanding of mutations was scientifically oriented but very fundamental. While Brian understood mutations to be "some kind of damage or some kind of freak gene put in the chromosome" [B 37], he had an alternative conception that inbreeding could cause mutation. [B 37] This alternative conception was also seen in Brian's written answers to the journal entry for the evolution of humans [Artifact 2], and the answers he offered in class. Brian realized that not all mutations were beneficial, "nothing comes of them," but he failed to recognize that many are harmful to organisms.

B: (Writing in reference to the evolution of speed in cheetahs) The slower cheetahs would die because of starvation and leave only the fastest. This would happen generation after generation until the very fastest could run 60 mph and his offspring would be the [species that survives]. (Pretest #7)

As demonstrated by this pretest answer, Brian recognized the importance of variation in a population to the process of evolution. As he explained, "Diversity is a big part of evolution." [B 123]. However, this recognition was not represented in either of the concept maps he constructed at the outset of the study. (See Appendix G for these concept maps.) This view is in stark contrast to his own species concept which will described in a later section.

The third aspect of Brian's understanding of the process of evolution is his conception of evolution as initially involving a small number of individuals in a population.

SD: So what's natural selection?
B: Natural selection is what keeps mutated organisms around.
SD: Okay.
B: and also keeps them from being extinct and dying out.
SD: Okay, and how does that work?
B: It's ah, the mutation, if it's one that works in the environment or ecosystem, or whatever, it goes to the whole community. The change occurs in the organism itself.
SD: Uh, uh. (Yes)
B: Like, either a single organism or a couple organisms. (B 50)

Brian recognized that natural selection operates on variation originally present in a small proportion of the population. He further explained that natural selection worked through causing the death of unfit individuals:

B: [Explaining a pretest answer] Population of ducks evolve webbed feet because most successful ducks without offspring. I mean, unsuccessful died without offspring. It's, that's natural selection and the ones that couldn't swim couldn't get the fish under water. So they just, ah, died off. (B 28)

This conception is slightly different from the more scientific conception of natural selection operating through the differential reproduction of members of a population.

Finally, Brian recognized evolution as changes in a population as opposed to changes within an individual:

SD: Okay. So when we talk about evolution do we say that an individual evolved?
B: Well, we all, like we change individually but we evolve together. (B 50)
B: An individual can change, but he's not actually evolving. (B 36)

Another conception related to the process of evolutionary change was Brian's collage understanding of fitness:

[In reference to the pretest question of the most fit lion]
B: Okay, C, Spot [the lion]. He had an adequate number of offspring and was able to change. He was good sized and had no apparent vulnerability to infection.
SD: Okay, so ahm, what does a biologist mean when she or he says fit? Like something is fit...
BR: I mean, if he can cope with what's around it and they can carry on....It has to have a number of offspring....They have to be healthy. I mean, you can't have it can't have ah vulnerability to little mosquitoes or something like that....It has to be able to live a long time. [B 29]

This collage conception of fitness differs from the scientific conception of fitness as having a high number of successful offspring. The collage conception was used by a large number of students in the class (54% on the pretest and 38% on the posttest).
This alternative conception has not been documented in the evolution education literature and it differs from the adaptive conception of fitness described by Bishop and Anderson (1990).

Brian was different from the other interview participants in that he understood the importance of geographic isolation in the process of evolution. This knowledge was reflected in his journal entry concerning the evolution of humans:

B: I believe the important change in our evolution is the tendency to stay in a group or tribe, rather than stray to find new females. This caused tribes to develop separately, creating probably slight differences. (Artifact 1)

The final conception to be discussed under the heading of process is Brian's understanding of genetic drift as a mechanism of evolutionary change. Genetic drift is a relatively advanced topic which is not often discussed in the classroom. Despite this, Brain experienced a conceptual change concerning this topic during the seven interviews used to describe his initial conceptions. At the outset of our interviews, Brian had no knowledge of genetic drift:

[In reference to the evolution of blindness in cave salamanders] B: Okay, salamanders could have been accidentally placed in a cave somewhere, some freak blind ones were born and stayed while the sighted ones left, leaving behind the blinded ones to reproduce.
SD: Okay, so that in your scenario, the sighted ones just walked away?
B: I man, I, I, that's the only way I could see it happening, the sighted ones just leaving. (B 33)

However, just 14 days later, Brian's comments while drawing a concept map revealed the initial construction of a conception of genetic drift [CM-2, initial].

SD: Okay, could you just read that [concept map] to me? Oh, we, we're missing one. [The term environment was not on his map, although he wrote it down in his initial list.]
B: All right. That's one that doesn't always affect it [evolution.]
SD: Uh, uh. (Yes)
B: So I'm just gonna' leave it out.
SD: Okay, so you, you put in environment but it doesn't always affect it. What do you mean by that?
B: Well there are instances when it doesn't.
SD: Uh, uh. (Yes)
B: It's just, just by chance.
The passage illustrates that Brian was beginning to understand that evolution could occur by chance, without the force of a selection pressure. This is a necessary conception in the construction of a scientific conception of evolution through genetic drift. While Brian did not yet have a name for this process, he was constructing the basis for this conception.

The second major group of conceptions that were evident in the initial interviews was Brian's knowledge of the broad theories of evolutionary changes. This characteristic has been alluded to earlier in the initial description of Brian's approach to biology. During our discussion of his pretest answers, Brian referred to theories of gradualism and punctuated equilibrium. He explained that these theories were useful because they helped explain the patterns of how the more narrow processes (e.g., natural selection) operate.

In Brian's initial conceptual framework, evolutionary theory was understood to explain natural phenomena that occurred after formation of "primordial soup." [B 158] He understood this "soup" to form when "little molecules got together and just happened to be able to function." [B 35] Brian did not understand biological evolution to describe the original formation of the earth, but instead the formation of life and subsequent changes in organisms.

Even in the beginning of the course, Brian had an appreciation of the importance of evolution in the study of biology:

SD: Ahm, so you think evolution is an important part of biology?
B: Uh, uh. (Yes)
SD: Why?
B: Just because, if you want to study biology, you have to understand why it's that way.
SD: Uh, uh. (Yes)
B: And to understand why, you have to understand how it became that way. (B 155)
In examining these data, the means of data collection should be remembered. The student participants and I discussed evolution on a regular basis, so it is not surprising to see Brian's answer to this question, as my presence may have prejudiced his response.

**History of evolutionary theory.**

While Brian had a skeletal knowledge of the construction of Darwinian theory and the structural theories which came after (punctuated equilibrium, gradualism), the history of science was not a major component of his conceptual framework. None of the historical hall-marks of evolution found a place in Brian's map or in his discussions. The omission of the historical aspect of the theory is not in conflict with Brian's scientific orientation. For Brian, knowledge of how natural phenomena works is fundamentally more important than knowledge of how that explanation was constructed.

**Evidence for evolution.**

Like the history of evolutionary theory, Brian's conceptions of the evidence for evolution were minimally used:

**SD:** Do you know any evidence that supports evolution?  
**B:** Ahm, well, we know there were other life forms because their bones are everywhere.  
**SD:** Do you know any evidence that refutes it?  
**B:** The Bible.  
**SD:** The Bible.  
**B:** Well, the, I don't know. Er, some religions don't believe it.  
**SD:** Uh. uh. (Yes) (B 155)

Unlike many of his answers to other questions, Brian's comments on supporting or refuting evidence were brief. It was difficult to gauge his conceptions on this matter, simply because it was so difficult to engage his participation in these discussions. It is significant that this scientifically, mechanistically oriented student would list the Bible as a source of refuting evidence. But because he resolved any difficulties he might have had with evolutionary theory long ago, evidence for the theory was not a major portion in Brian's framework.
**Nature of evolutionary changes.**

Because Brian had a largely mechanistic view of evolution, his conceptions of the nature of evolutionary changes are closely tied to his conceptions of process. At this point in the year, Brian understood that evolutionary changes in a population require a great deal of time to become apparent. However, time did not appear in the first two concept maps that Brian constructed (CM-1 & CM-2, initial) so this notion was not prominent in his conceptual framework.

During the initial interviews, Brian was constructing a conception of the random aspect of evolutionary changes. This change, described in the section on process, was a tentative one. As evidenced by his inability to account for a loss of a trait (blindness in salamanders), at the outset Brian understood evolution to occur only through natural selection driving a population toward the presence of a trait. This conception underwent a change during the fourth and fifth weeks of interviews. (See data in the mechanism section, p. 164)

Related to his initial conception of evolution as directional, Brian understood evolution as a process that "drives" organisms to a "higher level." [B 38] Brian had a vague definition for "higher" as being "more quality." [B 51] In Brian's conceptual framework, the notion of "higher" was equated to the role of the scientific conception of fitness. Brian was using an Aristotelian view of natural organisms at this point. But this conception is so poorly differentiated and loosely tied to Brian's greater conceptual framework, it is difficult to classify. In any case, this notion of "higher" is present, although not prominent, in Brian's conceptions of the patterns of evolutionary changes.

**Human evolution.**

Conceptions of human evolution are often closely tied to the students' conceptions of natural history. However, for some of the participants, issues of human evolution are so prominent in their conceptual framework, that these two groups have been separated. But in Brian's case, the issues of human evolution and his
understanding of natural history are inseparable simply because Brian viewed humans as being animals.

**B:** Like if we died off, there would be some other organisms that would move up in our place.
**SD:** Live in our place, what does that mean?
**B:** Well, we've, we could pick this, we could say dominate the planet right now.
**SD:** Uh, uh. (Yes)
**B:** So, something else has to dominate the planet, just like the dinosaurs did.
**SD:** Okay. So you kind of see us (humans) in the dinosaurs' place?
**B:** Uh, uh. (Yes) (B 40)

Not only did Brian have the declarative knowledge of humans as animals, he used that knowledge in explanations. In the quote above, Brian equated the ecological position of humans with that of other organisms. This quote also demonstrates that he viewed humans as being a species bounded by time and susceptible to natural forces, like dinosaurs. During a structured interview using a chart showing the pathways of primate evolution, Brian theorized about various selection pressures operating to make evolutionary changes within humans. [IAI-1, initial] Because Brian viewed humans as animals, Brian understood humans to be undergoing evolutionary changes through natural processes.

**Natural history.**

Brian had the greatest wealth of knowledge of natural history of the four interview participants. He explained that before taking Ms. Hurston's biology class the year before, all he really knew of the history of organisms on the earth was "just that dinosaurs existed." [B 34] Brian had a vague but scientific understanding of the historical record of biological organisms. He had some conception about the great age of the earth and knowledge that the physical characteristics of the earth have undergone radical changes during that long time span.

Brian's knowledge of the natural history of recent organisms underwent a change during the animal behavior section of the course:
SD: If you could sum up what you've learned from the animal behavior section, what would it be?
B: It's made me see animals as organisms rather than magic.
SD: Oh, that's nice. Okay, so what does it mean?
B: That they're actually living things.
SD: Uh, uh. (Yes)
B: It's not something you can hurl around like a baseball.
SD: Yeah. You've felt about 'em that way before or?
B: I don't know. The most contact I've ever had with a real animal was probably a dog.... I just think of it as it as my pet.
SD: So this whole section has helped you see them more as?
B: More like a dog for itself. (B 46-47)

I understand this passage to signify that the animal behavior section opened up for Brian an entire framework through which animals are organisms that can be studied and understood through scientific terms. This knowledge is relatively new and undifferentiated, however, as evidenced by his response to the interview about instances using animal graphics.

Brian demonstrated the greatest amount of animal lore of all the student participants in the interview about instances, but he often failed to draw many conclusions about the organisms shown [IAI-1, initial]. Most of his responses consisted of some article of knowledge about the animal pictured or a related animal. At the outset of the study, Brian was not prone to interpret organisms as assemblages of adaptations which could be explained or understood. However, he did use the notion of adaptation in an effort to explain the graphic depicting three species of bears and mused on why certain color adaptations would be beneficial for the animals' differing environments. Brian also applied his knowledge of evolution to attempt to understand the wing structure of a fruit eating bat.

B: I can't tell if that's four or five fingers on the wing.
SD: I don't know where the fourth one is. Does it matter if it has five digits?
B: Uh, uh. (Yes) So that it would make it split off later down the line than the birds.
SD: Okay. Split off later from what line?
B: Whatever it's split off from. (B 114)

Clearly while his knowledge of the bat wing structure is limited, Brian was trying to interpret characteristics within an evolutionary framework.
Evolutionary relationships.

In contrast to the importance Brian placed on the presence of variation in a population when discussing evolutionary changes, he used a somewhat typological species concept in discussions that explicitly addressed species concepts:

SD: And what about dogs, are they the same genus or same family or what?
B: Dogs are the same species.
SD: Same species? What does that mean?
B: That means they're just different breeds.
SD: Different breeds?
B: Like races and stuff.
SD: Uh, uh. (Yes) So what does it mean to be a species.
B: It means that they have real, they all have to be really similar. Ahm, and they all have four legs that they walk on. They have ears, eyes, nose, mouth, tongue. (B 85)

Brian simultaneously held two incompatible conceptions, variable and typological species concepts. But these conceptions were elicited by different cues. Questions concerning evolution revealed a variable species concept, and questions of other biological phenomena elicited use of a typological species concept.

Compatible with his typological species concept, Brian did not recognize that different species could not interbreed. Because the Darwinian species concept was not used by Brian, in several instances he tentatively suggested that hybridization between species could account for the origin of variation. He was not alone in the use of this conception. However, when Brian posed hybridization as an answer, it was always in a tentative and speculative manner unlike many of his classmates during whole class discussions.

Other biological processes.

Brian had a very firm knowledge of Mendelian genetics. He understood DNA to be the fundamental "blue print" for a species and this genetic material was usually passed in Mendelian terms. In the prediction interviews, he answered in a scientific manner, describing the independent inheritance of the characteristics between generations. He even had a sound knowledge of the action of sex-linked
characteristics. However, Brian's strict Mendelian conception of genetics can be contrasted with the more scientific view of the action of both blended and independently inherited traits.

Brian also displayed a functional knowledge of animal taxonomy. He could classify animals shown during the interviews about instances as well as explain the reasoning behind such classification. This functional knowledge was combined with an understanding that such classification should be linked to the organisms' evolutionary relationships.

Keeping with his mechanistic view of the natural world, Brian was not anthropomorphic in his explanations of biological phenomena. Additionally, he would reject anthropomorphic answers when they were presented to him.

**SD:** Can population make any changes in response to a selection pressure just by themselves?

**B:** No, you can't change the DNA. (B 67)

Related to anthropomorphism, Brian understood there to be a difference between behavioral characteristics of organisms and genetic characteristics. In discussions for the sorting task, Brain explained that the rabbits could change their behaviors, but they could not change their genetic makeup.

See Figure 10 for a summary of Brian's conceptual framework at the outset of the study.

Mid-year framework

**Mechanism.**

Brian's understanding of the mechanism of evolutionary change continued to be the most prominent aspect of his conceptual framework for evolution, and many aspects of his initial framework were retained through the mid-year period. He retained use of conceptions of (a) mutation as the source of variation, (b) variable species concept, and (c) evolution as being a change in the proportion of a population with a
trait. The concept maps he drew at the beginning of the year were not substantially different from those he drew at mid-year (CM-2 & CM-3, mid year).

<table>
<thead>
<tr>
<th>Human Evolution</th>
<th>Characteristics of Evolutionary Changes</th>
<th>Broad Evolutionary Theories</th>
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<tbody>
<tr>
<td>Humans are animals which evolve</td>
<td>Random aspect of evolution</td>
<td>Evolution includes changes since primordial soup</td>
</tr>
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<td>Humans are primates</td>
<td>Long time required</td>
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<td></td>
<td>Drive toward higher organisms</td>
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<td>Evolution important in biology</td>
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<tr>
<th>Evidence for Evolution</th>
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<tbody>
<tr>
<td>Fossils are supporting evidence</td>
<td>Mutation as the origin of variation</td>
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<tr>
<td>Biblical evidence is refuting</td>
<td>Variable species concept</td>
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<td>evidence</td>
<td>Evolution as a change in proportion of</td>
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<td>population</td>
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<td>Collage concept for fitness</td>
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<td>Genetic drift</td>
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<th>Related Biological Knowledge</th>
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<tr>
<td>Mendelian genetics</td>
<td>Populational and typological species</td>
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<tr>
<td>Rejection of anthropomorphism</td>
<td>concept</td>
<td>Old, changing earth</td>
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<td></td>
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<td>Knowledge of animal taxonomy</td>
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Note. Italics indicate instances of conceptual change. Solid block indicates academic conception.

Figure 10
Summary of Brian's initial conceptual framework for evolution

However, there were some subtle changes seen in the conceptions in the mechanism category. The first of these changes was seen in Brian's recognition of the prospect of harmful mutations. The first concept map he drew during mid-year demonstrates that Brian's tentative knowledge of the existence of harmful mutations became enmeshed into his conceptual framework for this aspect of evolution. (See Appendix G for Brian's concept maps.)

**Brian:** Some mutations can have real disadvantages to it. And, if it is a bad mutation, natural selection will make that individual die. Ahm, which would make it not have any offspring which, if it was a separate species of whatever, then it would be extinction. (B 213)

Related to this, Brian formed a more structured knowledge of the random aspect of mutation, "mutations and all that are just by chance, they just happen to fit." (B 169) Through introducing a greater importance of the random aspect of mutations,
Brian further separated the actions of mutations and natural selection, "Natural selection doesn't cause mutations." (B 213) This separation is further demonstrated in his answer to the interview about instances session which concerned the production of mutations in bears (PI-1, mid year). In this question, Brian explained that both beneficial and harmful mutations were equally likely to occur, even in the face of a strong selection pressure.

Brian's collage conception of fitness also underwent a subtle change during mid-year. In response to the sorting task, Brian explained that the operation of natural selection increased the "survivability" of members of a population. [B 214] However, it is important to remember that while Brian had an operational understanding of the scientific conception of fitness, he did not associate the term "fitness" with this scientific conception.

Brian began to question his initial conception of inbreeding as a source of new variation during the mid-year period. In a discussion of factors which may affect the mutation rate of a population Brian asked, "Does inbreeding actually cause mutations, or is it just allow for recessive traits to appear?" Inbreeding had not been brought up in our conversation, although it had been offered by a student as a possibility in a whole class discussion that occurred five days earlier. The manner in which this question was asked demonstrates that Brian had already begun to answer this question for himself.

Evolutionary changes.

The group of conceptions related to the nature of evolutionary changes was the second most prominent category of Brian's conceptual framework during the mid-year period. The first change seen in this category was his strong emphasis of the random aspect of evolution. This change was described in the preceding section on the process of evolution. The employment of the random aspect of mutation resulted in substantial changes in Brian's conceptions of the nature of evolutionary changes. While Brian had
tentatively considered the random aspect of evolution earlier in the year, at mid-year this became a very prominent aspect of Brian's understanding of the nature of evolutionary changes. The following quote from a discussion of word sort demonstrates that Brian had a well defined understanding of the nature of evolutionary changes (WS, mid-year):

B: All evolutionary changes are random.
SD: Uh, uh. (Yes)
B: It goes with chance.
SD: Uh, uh. (Yes)
B: Random and chance, but the end result can show order. (B 226)

Brian's conception of the random aspect of evolutionary changes was also demonstrated by his selection in the interview about instances of evolutionary patterns (IAI-3, mid-year). In this exercise, Brian selected the phylogenetic tree which had the most irregular branching pattern. (B 185)

Related to this conception of randomness, Brian understood evolution to operate without a grand, overarching design. Following the class activity in which natural patterns were discussed, Brian explicitly rejected the existence of a design or plan behind the action of evolution. His rejection fits well with the random aspect he had so recently begun to use.

But by saying that evolution followed no plan or design, Brian was not suggesting that evolution did not have a purpose (i.e., function). In the questions Brian completed for the class discussion of natural patterns he explained, "evolution has a purpose, but not intentionally." (Artifact 5) Purpose was understood to be "progressions" in an organism from less to more complex, and "moving organisms higher on the evolutionary tree." (B 167-168) Supporting this movement, Brian explained, "To go from a paramecium to a human being, I call that progress." (B 167)

Brian's Aristotelian understanding of biological diversity was tempered by his recognition of evolution as being a tree (as opposed to a ladder of life).
While Brian understood evolution as making groups of organisms more complex, this complexity was interpreted as how well they are adapted for their particular niche, "parameciums [sic] are pretty perfect for what they have to do." (B 168) There is a tension here between Brian's understanding of evolutionary progression and his understanding of evolutionary adaptations. At this point in the interviews, this tension was not resolved.

Brian understood evolution to be a natural process through which species change in response to ever changing natural conditions.

**SD:** Would you say extinction is a failure of a species?
**B:** Uhm, no, the species didn't fail. The species just wasn't capable, I mean it wasn't like a test....But, I don't know, it's just the changing of the stuff around 'em.
**SD:** Uh, uh. (Yes)
**B:** So it's not really a failure, it's just like a change in time. (B 166)

**Natural history.**

The third most prominent category of conceptions during the mid-year period was Brian's knowledge of natural history. When asked about the history of biological organisms on the earth, Brian drew a very elaborate, detailed time line. He explained (a) the earth was 4.5 billion years old, (b) life required water accumulation, and (c) the chance organization of the first organic molecules into simple systems such as plasmids. His time line included formation of the first multicellular organism, the formation of the first plants and animals, and the exploration of land by the first semi-terrestrial vertebrates. He ended the time line with further development of both animals and plants. (B 176)

Related to his conception of evolution being the natural result of organisms living in a changing environment, Brian understood the earth to be undergoing continual, slow change, explaining how plate tectonic theory would account for many of these changes.

Another aspect of Brian's natural history knowledge was the distinction he drew between instinctive and learned behaviors. He realized that many of the behaviors of
organisms are genetically determined (instinct), but these could also affect how organisms learn. This issue became important as he considered which traits were viable options for evolutionary changes.

**Evolutionary relationships.**

The most definitive change seen in this category of conception was a change in Brian's species concept.

SD: Do you think that a species is something that really exists whether we put a name to it or not?
B: Well, there's always organisms that are similar, but they're different. And the ones that are similar stay together.
SD: Uh, uh. (Yes)
B: Well, depending on their nature. But they reproduce together.
SD: They reproduce together? Is that something really important when we talk about a species, that they reproduce together?
B: Um. Yes. Cause if it didn't reproduce together, you wouldn't have a species. (B 218)

From his formal, typological species concept seen in early interviews with Brian, this modified version has emerged. Brian introduced the lack of breeding barriers as an essential characteristic of a species. His last comment in the above quote demonstrates that this was a substantial change, with Brian rejecting his earlier conception.

**Other biological processes.**

Brian's knowledge of genetics underwent a change that may be related to the modifications of his conception of process and the nature of evolutionary changes. While his early conceptions represented a sound, scientific understanding, these underwent a further reorganization that allowed for a more sophisticated understanding of both the random and constrained aspects of inheritance:

SD: Do you think the way you look, is it random or is it ordered?
B: Ahm, I mean, there's, I mean there may be millions of combinations that they could have had.
SD: Yeah.
B: Between my mom and my dad. But, they're just specific like if you could put 'em all, I mean, you wouldn't be able to list 'em all.
SD: Uh, uh. (Yes)
B: And they're just random what way. I mean, was the one that grew or whatever.
SD: Okay, so it's a combination of
B: I mean there's a set number.
Other categories.

The conceptual categories of the evidence for evolution, broad evolutionary theories, human evolution, and the historical aspects of evolutionary theory underwent no revisions during this period.

See Figure 11 for a summary of Brian's mid-year conceptual framework.

Year-end framework

Natural history.

Conceptions related to natural history were the most prominent group in Brian's year-end conceptual framework. As shown in the previous two descriptions, Brian retained a well differentiated knowledge of many aspects of natural history. But in the interviews conducted toward year's end, not only did Brian have a wealth of knowledge of natural history, there were also signs of a growing interest in this area as well. While Brian continually asked questions during our 17 interviews, toward the end of the year most of his questions concentrated on information about various animals.

Some examples of his questions include:

Do female (elephants) have tusks? Do the males? (B 241)
Do African elephants have the bigger ears? (B 241)
Why don't the females have tusks? (B 242)
Can bears move their ears like dogs? (B 250)

These questions not only demonstrate an interest in natural history, I feel they signify Brian's expectation that there are causes and results for various adaptations. Use of evolution as a unifying theory base allows for such an expectation.

Other signs that Brian had begun to use evolution as a means of understanding natural history came from a discussion of the graphic depicting three species of bears:

SD: So do you think they are the same species?
B: Ahm, I don't know. They're related.
SD: Yeah?
B: Uh, uh. (Yes)
SD: You say that based on just their looks? They look the same?
B: Well it's like the bottom two [a grizzly and black bear] are more related than the polar bear.
SD: Is that just because of the size difference or ah the color difference?
B: Well their snout and stuff are different....Ahm, probably these two separated after both of these ones separated from the polar bear. (B 249)

Human Evolution
Humans are animals which evolve*
Humans are primates*

Evidence for Evolution
Fossils are supporting evidence*
Biblical evidence is refuting evidence*

Characteristics of Evolutionary Changes
Conceptual change for random aspect of evolution
Long time required*
Lack of design for evolution
Evolutionary progression vs further adaptation

Evolutionary Relationships
Darwinian species concept

Related Biological Knowledge
Mendelian genetics*
Rejection of anthropomorphism*
Genetic inheritance is a random process operating within constraints

Mechanism
Mutation as the origin of variation*
Variable species concept*
Evolution as a change in proportion of population*
Genetic drift*
Recognition of harmful mutations
Fitness as an increased "survivability" of organisms

Broad Evolutionary Theories
Evolution includes changes since primordial soup*
Punctuated equilibrium*
Gradualism*
Evolution important in biology*

Historical Aspects of Theory
Natural History
Connection of learned and instinctive behaviors
Elaborate knowledge of history of life on earth
Old, changing earth*

Knowledge of recent natural history of animals*
Knowledge of animal taxonomy*

Note. Italics indicate instances of conceptual change.
* indicates retention of conception from previous description.
Solid block indicates academic conception.

Figure 11
Summary of Brian's mid-year conceptual framework for evolution

Another aspect of Brian's conception of natural history was his conception of the competitive basis of biological systems. He explained that organisms compete for a limited amount of natural resources, "to stay alive and reproduce they need to have certain things. They have certain requirements." (B 274) The conception that there
are natural limits to the number of organisms a system can sustain is an absolutely essential one to understanding the process through which evolution works (Fisher, 1992).

**Mechanism.**

Like the previous descriptions, Brian's conceptions of the mechanism of evolutionary change were prominent. He continued to use conceptions of (a) mutations as the source of variation, (b) a variable species concept, and (c) evolution as being a change in the proportion of a population with a trait.

While these three portions were retained, Brian's conception of natural selection underwent subtle revisions during this period. Previously, Brian understood natural selection to operate through the death of less "survivable" individuals. As he elaborated on his posttest answers, Brian explained how natural selection operated on a population of ducks:

**B:** Less successful ducks just died without offspring. Well. (Pause)
They didn't, they didn't, like the less successful ducks didn't just all die one year because all the more successful ducks just took over.

**SD:** Okay.

**B:** They, they just eventually got weeded out. (B 295)

While this conception was expressed in very informal terms, there is evidence that Brian was beginning to recognize natural selection as a more subtle force than he previously had described.

Brian's conception of fitness was still under transition at this point of the year. He understood that high survivability was important in evolutionary terms, but he had difficulty weighing the importance of this characteristics against their "adaptability." (B 297) Brian explained that if a lion with a higher survivability but low adaptability continued to reproduce and the environment of this population changed, the entire population could be eliminated. Brian used a population approach to fitness which remained at odds with the scientific understanding of this conception.
On the posttest, Brian remained unable to use a scientific conception of genetic drift to explain the elimination of sighted salamanders from the cave population. While this conception was undergoing changes during the school year, by the end of the research Brian had not yet constructed a meaningful scientific conception for this topic.

During previous descriptions, geographic isolation played a role in Brain's understanding of the process of evolutionary changes. He retained the use of this conception as signified by its inclusion in Brian's list of terms for a conception map, but this concept did not appear in the formal map. Brian could not find a way to easily include this term in his map, so it was omitted. This action represents an important research consideration. As can be seen here and in later examples, concept maps include only a portion of a student's conceptual framework for a topic.

The third most prominent aspect of Brian's year-end conceptual framework was the group of conceptions describing the nature of evolutionary changes. All the conceptions described previously were retained, with one major change in this category. Brian began to apply the conception of adaptation much more frequently in the final series of interviews than he had previously. By year-end, Brian used a fairly scientific conception of adaptations.

**SD:** What is an adaptation?
**B:** [Pause] Ahm, an adaptation is a change
**SD:** Uh, uh. (Yes)
**B:** in the gene structure allowing the organism to be better fit for what it needs to do.
**SD:** Uh, uh. (Yes). What causes an adaptation?
**B:** A gene change.
**SD:** A gene change.
**B:** A mutation.
**SD:** A mutation. So an adaptation is caused by a mutation.
**B:** [Shakes his head yes.]
**SD:** But they are not the same thing? You wouldn't use a mutation and an adaptation the same way?
**B:** No.
**SD:** No?
**B:** Mutations happen all the time.
**SD:** Uh, uh. (Yes) And adaptations?
**B:** Adaptations are mutations that worked. (B 254)
Brian used two of the three formally accepted explanation for adaptations (Lucas, 1971), and he recognized the subtle difference between the meanings between these terms.

**B:** Well there are two different kinds of adaptations....The way that I was talking about it, is one of them is an actual change in the organism.
**SD:** Uh, uh. (Yes)
**B:** Or you can change your behavior. (B 254)

Another sign that adaptation had become an important aspect of Brian's understanding of evolutionary change was the concept map that he drew which focused solely on adaptation. This adaptation map was drawn in response to the request "map your understanding of how evolution works" [CM-2, year end]. (See Appendix G for this concept map.)

**Evolutionary relationships.**

By the end of the year, the tentative use of the Darwinian species concept had become fairly well established in Brian's conceptual framework.

**B:** How is a species defined? Is it like organisms can ah recognize each other and mate with each other? (B 290)

The manner in which this question was asked signifies that Brian was already convinced of the answer representing a shift from the far more tentative usage of this conception seen at mid-year.

**Broad evolutionary theories.**

Brian's responses during the final series of interviews further demonstrate his fondness of broad theories. However, his conception for what is included in the scope of evolutionary theory was under revision at this point.

**SD:** So when we're talking about organic or biological evolution, do you think, what does that term encompass?
**B:** Ahm, well we know it includes the change in a species.
**SD:** Okay.
**B:** I haven't thought about that before. I guess, if you take the literal meaning of the word evolve, you'd have to go from one state to another.
**SD:** Uh, uh. (Yes)
**B:** So, [pause] I guess [pause] I don't know if it would include the creation of species or not. (B 278)
The actual limits of evolutionary theory were not a topic Brian had invested much time or energy in considering. Because of this, one question was capable of causing a change in his conception for this topic.

The conceptual groups of the historical aspects of evolutionary theory, human evolution, evidence for evolution, and knowledge of outside biological areas underwent no substantial changes from the previous description.

See Figure 12 for a summary of Brian's year-end conceptual framework.

Summary of year long conceptual change

As shown in Brian's maps, his emphasis has shifted at year-end to a more holistic view of the evolution. While his maps constructed at year-end heavily stress the mechanism of evolutionary change, this is not their sole component. Brian experienced several instances of conceptual change between this last description and that made at mid-year. He began to recognize that adaptations of organisms can be understood through the application of evolutionary theory. His view of natural selection changed from a somewhat simplistic conception of survival of the fittest toward an understanding of differential reproduction. The final series of interviews elicited expression of a somewhat sophisticated understanding of the various forms of adaptation. While Brian had a firm, basic understanding of evolution at the outset of the study, several facets of this conceptual framework became refined during the school year. Overall, the pattern of Brian's conceptual change was toward a more scientifically acceptable understanding of evolution.

Stephanie: Biologist as Multi-disciplinary Realist

I selected Stephanie as one of the first of choices for interview participants based on her critical attitude and interest in biology. From the outset of the interview process, Stephanie made clear to me her skepticism of evolutionary theory. At the same time, she demonstrated great interest in the research process, and she offered to participate long before I asked for volunteers. Her skepticism and interest were also
combined with the use of several alternative conceptions in her explanations of evolutionary process. Stephanie's case is particularly useful in its implications for the actions of a learner's conceptual ecology on the process of conceptual change.

### Human Evolution
- Humans are animals which evolve*
- Humans are primates*

### Characteristics of Evolutionary Changes
- Evolution involves random changes within constraints*
- Long time required*
- Lack of design for evolution*
- A more complex, scientific conception of adaptation

### Broad Evolutionary Theories
- Evolution includes changes since primordial soup*
- Punctuated equilibrium*
- Gradualism*
- Evolution important in biology*

### Evidence for Evolution
- Fossils are supporting evidence*
- Biblical evidence as refuting evidence*

### Evolutionary Relationships
- Darwinian species concept

### Historical Aspects of Theory

### Related Biological Knowledge
- Mendelian genetics*
- Rejection of anthropomorphism*
- Genetic inheritance as a random process operating within constraints*

### Mechanism
- Mutation as the origin of variation*
- Variable species concept*
- Evolution as a change in proportion of population*
- Genetic drift*
- Harmful and beneficial mutations
  - Fitness as an increased "survivability" of organisms
  - Natural selection operates on differential reproduction

### Natural History
- Connection of learned and instinctive behaviors
- Elaborate knowledge of history of life on earth
- Old, changing earth*
- Knowledge of animal taxonomy*
- Knowledge of recent natural history of animals*
- Adaptations as explainable phenomena

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Note. Italics indicate instances of conceptual change.
* indicates retention of conception from previous description.
Solid block indicates academic conception.

**Figure 12**
Summary of Brian's year-end conceptual framework for evolution

Stephanie was a senior girl who sat in the back of Hurston's Biology II class. While she spoke only occasionally to the entire class, I often watched her whisper comments to fellow students during whole-class discussions. Like Brian, Stephanie volunteered responses in whole-class discussions only if the answer wasn't immediately forthcoming from another student. Our first interviews were difficult because of Stephanie's very direct mode of communication. She offered to answer
only to the specific questions that were asked: she did not follow tangents arising from our conversations. But as the interviews continued, I learned to use Stephanie as a valuable resource. Being very precise in her choice of words, she could react in many different ways to one question depending on how the question was worded. More than once, I found myself correcting my interview protocols for the next week based upon Stephanie's tutelage.

The most insightful descriptor of Stephanie's approach to biology is as a multidisciplinary realist. Her approach is demonstrated by her comments made before drawing a concept map for "her understanding of evolution" (CM-1, initial):

SD: Write down some key concepts that you think you need to explain [evolution]....
ST: Okay, I'd put down ah I think this is the name of it, Origin of Species....Okay, let's see, probably the Galapagos islands.
SD: Uh, uh. (Yes)
ST: Let's see ah. Neanderthal. [Long pause] I can't remember any of the scientists' names, but I just know there's some guy
SD: Yeah
ST: That, the primordial soup thing....[Whispering] Ah, I don't know what else to put down. [Long pause] I guess I can put down CroMagnon also.
SD: Okay.
ST: And then, the Leakey family. I guess I'm more into archeology than biology. [Laughs.]
SD: Yeah, I can see that....
ST: All right. I don't know the term for it, but you know how ah, the embryos from the different animals look the same.
SD: Uh, uh. (Yes)
ST: I know there's a term for it.
SD: Ah, ah. Uhm, ontogeny recapitulates phylogeny?
ST: That's it.
SD: Okay....You've made facial gestures and stuff when you talk about primordial soup.
ST: I just don't think that's right.
SD: You just don't think that's right. What do you think is right?
ST: Well, I'm sort of creationist evolutionist. I'm kinda' both.
SD: Okay.
ST: So, but I just don't think that life could start from a bunch of chemical mixing together.
SD: Okay. (Yes)
ST: And, ah, what I once told my friends, then who put all the soup together?
SD: Yeah?
ST: [Small laugh] That's just one thing that I've thought of. So I think that it's possible that life was created from God and then evolved from there. I just don't think that life was created from primordial soup.
SD: Uh, uh. Is that something you came up with on your own? . . .
ST: Yeah.
SD: Yeah, you know we've talked about this in some ways before. Ah, how do you feel about this, the continuation of the Galapagos and Darwin . . .?
ST: Oh, well I think that Charles Darwin probably had a lot of good points
SD: Uh, uh. (Yes)
ST: Because I think it's possible that some species developed from others or whatever. Whatever it said in his book. But ah, the ontogeny recapitulates phylogeny thing, ah, I mean that's interesting. Maybe it's meant to be that the development starts the same.
SD: Uh, uh. (Yes)
ST: I don't know if that's right or not. I haven't made up my mind, whether they have truth in that or not. (D 37-45)

When asked to map her understanding of evolution, Stephanie did not approach the task as a mechanistic biologist with a dissection of the process, or even as a functional biologist with an explanation of patterns which result from evolution. Instead, she provided an account of what she felt were the important stages of evolutionary theory and the scientists responsible for them - Darwin and the original theory, the primordial soup "guy" and his explanation of the origins of life, and the Leakey family and their theories of human evolution. Stephanie did not use just one way of understanding of world; she used many. Her concept map demonstrates a historical/sociological approach to biological knowledge. As she explained, "I don't really see any importance to just knowing something just purely scientific." (D 283)

When I refer to Stephanie as "multi-disciplinary," I mean to say she used the knowledge from a variety of disciplines to understand biology.

The second part of Stephanie's descriptor, realist, may be considered problematic by many science educators, but I feel the appropriateness of this term is also demonstrated in the interview segment shown above. When I asked about the facial expression she made while writing about primordial soup, she responded, "I just don't think that's right." Stephanie recognized the existence of a external, physical reality that could be described and understood. While Stephanie was a realist, she was not a scientific realist; she did not always choose to understand the reality in scientific terms.
Instead, she referred to the knowledge of many disciplines and ways of knowing in order to construct her understanding of reality. This is represented by Stephanie's reaction to the graphics depicting biological organisms (IAI-1, initial). During these interviews she explained, "I'm giving you scientific answers. I think that's what you want." This passage indicates that Stephanie understood that there are many ways to interpret nature. (D 239)

As suggested by her approach to biology, Stephanie has a wide scope of academic interest. She enjoyed studying most disciplines, although English and history were her favorites. Mathematics was the only subject Stephanie rejected as being difficult, uninspiring, and inapplicable to her own life. Stephanie particularly enjoyed biology and planned to pursue a profession in biomedical technology. However, Stephanie's most ardent interest was in archeology. She studied the subject for several years, and had been a docent in the archeology section of the neighboring university. However, she decided not to pursue this avenue professionally as she recognized the limited positions available in this area.

Stephanie was a responsible student, completing assignments long before they were due. Out of school, Stephanie spent much of her time reading. Stephanie's father described her as a "voracious reader." [D 307] He explained that, like her mother, she would begin one novel soon after finishing another. Some of the titles she read during the study included *Fountainhead, Jurassic Park, The Kitchen God's Wife, Notes from the Underground, Clan of the Cave Bear,* and *Brothers Karamasov.* Her father explained that she never limited herself to one area and she her reading always spanned a broad area.

In our interviews, I was struck both by Stephanie's literary sophistication and her self-assurance. As described by her parents, Stephanie spent a great deal of her life in the company of adults, and she was very comfortable participating in conversations with adults. In our interviews, Stephanie was open, interested, and critical. She was
very comfortable in taking a position and defending it as she looked for the flaws in her own and other's arguments.

**Stephanie's Conceptual Ecology**

The most influential aspect of Stephanie's conceptual ecology of evolution was her distinct religious orientation. Activities at a Methodist church consumed much of her free time. Consistently she found the weekly Bible study to be a highlight of her week. In this Bible study, students came together with a knowledgeable adult for very in-depth religious discussions. Often Stephanie would recall for me with vivid detail the discussions of the previous week. This is not to imply that Stephanie's religious understanding subsumed all other types of knowledge:

**ST:** If there's a discussion in one of my classes, I kinda', I'll think about it after class, or something will trigger it when I'm walking down the street or something, and I'll just think about it. I think a lot of the philosophy that I've found just by doing reports for my World History class I think about a lot.

**SD:** Oh, do you?

**ST:** Uh, uh. (Yes)

**SD:** You like that sort of thing?

**ST:** Yeah. I have Bible study once a week, and so that kind sometimes, it contradicts what I'm learning.

**SD:** Uh, uh. (Yes) What do you do about that then?

**ST:** I just think about it. I don't know. It's kind hard to, hard to chose you know, which is right. (D 151)

When evolution was discussed, Stephanie placed the highest value on knowledge stemming from her belief system. Stephanie acknowledged that subtle forms of evolution could occur, but she rejected the conception that humans are the result of evolution from a ancestral primate. Instead, Stephanie was a biblical literalist in this regard:

**ST:** Oh, ah, in church, when they say well God created man, and I think, well it's probably true. (D 28)

Stephanie could be classified as a progressive creationist using Nelson's (1986) classification system because she understood each biological group to be a result of special creation, although she understood that each group could undergo a progressive
form of evolution. There is an additional facet to Stephanie's understanding in this regard:

**ST:** I think that maybe things that are similar, like Neanderthal man, kind of evolved into us supposedly. I think, I can see how that could happen. Just they're just subtle changes. (D 25)

At the outset of the study, there is evidence of Stephanie's multi-disciplinary approach to a phenomenon. Here she was blending knowledge from religion, anthropology, and biology to construct a foundation for her acceptance of evolutionary process. I found her views to be similar to her parents, as they too understood much of nature through a religious framework. However, Stephanie's conception of human evolution differed drastically from her father's who used a more traditional, biblical understanding. As the study progressed, the scientific phenomena that Stephanie would accept underwent subtle modifications. These modifications will be discussed as her frameworks are described.

Related to her strong religious orientation, Stephanie understood the human life to have a fundamental theistic component:

**Stephanie:** I think everything happens for a reason. . . . I think, there's probably something I'm supposed to learn from this. (D 56)

But unlike the students described by Cobern (1992), Stephanie did not hold this theistic or religious view for all of nature, only that which directly impacted humans. For the majority of the natural world, Stephanie used a mechanistic or naturalistic understanding.

Stephanie's positive scientific orientation may have provided for her partial use of the naturalist world view. She enjoyed studying biology, saying "I think it's fascinating to figure out why things are." ([D 31] She particularly enjoyed studying the aspects of biology that helped her understand the humans, and "What's more important than learning about yourself?" (D 32) For Stephanie, for knowledge to be important it had to impact on her life, "I don't really see any importance to knowing something just purely scientific." (D 283)
Stephanie approached most of the areas of biology as a scientific realist. She rejected the existence of many pseudoscientific topics (Lock Ness Monster, aliens) immediately. In response to questions that clearly have a scientific basis, Stephanie reacted as rational, scientific realist. However, she was not always a scientific realist:

**SD:** For something to be true it has to have a scientific basis for you?
**ST:** Not necessarily...
**SD:** How do you make that flip flop? How do you know whether to analyze things scientifically or through some other means?
**ST:** Well scientifically if I read about it and there's a fact and they have proof on a microscope slide.
**SD:** Uh, uh. (Yes)
**ST:** I can go in and look at it. That's different then having somebody say "Well this might be the way things are." Then I can just think about it and think about what the possibilities might be for accepting something. Or ah, what I , what I believe personally. Whether I'm Buddhist or Lutheran or whatever. (D 57)

When Stephanie was formally asked about the boundaries between science and religion, the definitions seemed clear. She explained:

**ST:** See religion works on faith and science works on fact.
**SD:** Okay, so what is faith?
**ST:** Faith is the belief in something even if you can't see it or hear it. You just have to know that it is. Whereas science doesn't know anything until it's proven and written down and made a theory of or something. (D 201)

But Stephanie perceived many intersections between the two ways of knowing. Stephanie's case study is an important one as it provides an opportunity to describe the nature of the intersection between academic and belief based conceptions.

Within science, Stephanie's epistemology was much like Brian's. She was typically a scientific realist, understanding the goal of science to find out the "truth." (D 80) But like Brian, Stephanie did not always use a realist understanding of knowledge. When she was comparing theories which did not have great personal relevance, she had a distinctly relativistic approach. In these conditions, she discussed the tentative and contextual nature of knowledge. But also like Brian, when she discussed theories with great personal relevance or universally accepted theories, Stephanie approached this knowledge as a realist with the understanding that this
knowledge somehow approximated nature. This fluid epistemological approach, while
it may be incoherent to those who study philosophy or logic, has been documented
previously in a group of biologists (Abrams & Wandersee, in press).

For Stephanie, a scientific theory is much like a hypothesis that has been "proven
and you think that's the truth." (D 80) She explained that if "everyone agreed on a
theory," it would become a fact. (D 81) This alternative conception fits well with her
use of the realist epistemology, in that she views science as a search for universal
truths.

One attribute of Stephanie's fluid epistemological stance was that it allowed her
to recognize the attributes of theories she did not personally accept. The division
between what Stephanie accepted and what she understood became a large factor in the
conceptual change that was documented.

ST: My personal view is that I kind of go with creationism. But I can
see how the theory of the development from one cell could come to be,
but I just don't really think it would work. (D 71)

Stephanie did not accept scientific knowledge simply because it was presented by
an authority. This position made Stephanie very aware of the ways in which her
knowledge differed from scientific knowledge. She expected to understand scientific
explanations, but she did not always expect to accept these explanations as personal
truths. She drew clear distinctions between personal and academic knowledge, and
therefore these distinctions were relatively easy to document. This is not be the case
for the other participants. While she realized that her understanding of biology was
limited, she was not aware that her academic conceptions differed those of science.

Stephanie's Conceptual Framework for Evolution

Initial framework

ST: I believe evolution is a possibility because of all of the evidence
that supports the theory, such as Lucy and finding the ancestral bones.
But I don't think, I don't completely believe that man crawled out of the
sea a million years ago. [Soft laugh] Man may have evolved fully from
Neanderthals, but not fish or one celled organisms. I don't think just
because I would decide to live in the ocean that my great grand children would have gills. That's pushing the evolution thing too far. (D 24-25)

The above quote is Stephanie's answer to the pretest question, "What is your personal opinion of the theory of evolution?" This answer signifies Stephanie's (a) recognition of viable scientific evidence supporting evolution, (b) conception that a scientific description of evolution includes large scale morphological changes dependent upon a Lamarckian mechanism, and (c) personal conception that human evolution includes only subtle changes within hominids. Each one of these individual conceptions are important in describing Stephanie's initial conceptual framework, however, her conception of the nature of evolutionary changes was particularly influential and will be discussed first.

Evolutionary changes.

As demonstrated in her second concept map (CM-2, initial) and the preceding quote, Stephanie had two conceptions of evolution. The one that she personally accepted was that evolution was a process of gradual, subtle changes that occurred within a kind of organism after the initial act of creation. As Stephanie explained, "I could see how that could happen. Just because they're subtle changes. Just adaptation to your environment." (D 25)

Stephanie understood that the scientific explanation for evolution to involve a process of drastic changes that accounted for the original production of life and a subsequent series of large scale morphological alterations which forced organisms to "totally change into other creatures." (D 94) Stephanie rejected this group of conceptions as being implausible:

ST: I think a species can evolve... Cheetahs, that a species that just kind of grew, evolved into something better. But that whole things about the amoeba [evolving into humans].
SD: What would you think an evolutionist would say happened to an amoeba?
ST: I think that's really pushing the point. You know, when somebody says that. But you know they say it happened over millions of years. But even then, something had to just make something happen. If I didn't have it, I couldn't just grow into something myself. And I don't
think the amoeba group could have evolved either. They don't, they
don't have the traits to do that with. I don't see how it could happen. (D 28)

Stephanie had two systems of conceptions of the nature of evolutionary changes,
the one that she accepted and personally applied, and the one that she understood
science to hold but she personally rejected. But, as shown in the concept map drawn
early in the study, Stephanie did understand these two conceptual systems for evolution
as having a common component of natural selection. Stephanie personally accepted and
applied natural selection in her explanations of change in a population. Stephanie's
conception of natural selection included a driving force in the form of 'the drive for
survival of a species.'" (D 29) This alternative conception will be further discussed in
the following section.

Within both systems of conceptions for evolutionary changes, Stephanie had
several alternative conceptions. Like Brian, she used an Aristotelian concept of
evolution as a progression to a "superior" organism:

SD: Do what do you think evolution is? When we say something
evolved, what does that mean?
ST: It turns into something better. (D 26)

Within her system for the scientific explanation, Stephanie understood evolutionary
changes to involve the progressive changes within a group of organisms, a change that
should logically end with the production of only humans:

[In reference to a graphic depicting a gorilla]
ST: So why did [scientific] evolution stop with that particular gorilla?
Why didn't he evolve all the way up into humans?
SD: Okay.
ST: So I think if this was right [pointing to graphic of hominid
evolution], then there would only be humans. (D 96)

Stephanie rejected the scientific explanation for evolutionary changes because of
what she perceived as several weaknesses of the explanation. One of these weaknesses
described in the quote above was the existence of other forms of life other than humans.
Another area of weakness was the inability of science to reproduce the initial production
of multicellular life:
ST: But see development from one cell, I just don't see 'cause if that happened once then maybe that could happen again. So maybe we could see evolution happening over a period of a hundred years or something.
SD: Uh, uh. (Yes)
ST: and we haven't. It's only happened once, and that's why I just don't believe that. (D 72)

Stephanie also had difficulties understanding how the scientific explanation of evolution could account for such "drastic changes" as "how scales changed to feathers. That's such a difference. I don't see that." (D 95)

Another conception that Stephanie had for this group concerned adaptations. Stephanie understood adaptations to be a behavioral or genetic change which occurs within a group of organism over many generations. This conception represents an instance in which Stephanie's personal understandings coincided with her scientific conceptions. While Stephanie used the scientifically accurate conception of adaptations as occurring within a population and requiring long time periods, she failed to differentiate the many different scientific meanings of the term "adaptation."

Mechanism.

Stephanie had several alternative conceptions related to the mechanism of evolutionary changes at the outset of the study. Once again, the analysis is complicated as we consider the two explanations in Stephanie's conceptual framework, her personal conceptions and her conceptions of the scientific explanation.

Conceptions related to the origin of variation are the most difficult to understand. Within her personal explanation for the origin of variation, Stephanie understood "interbreeding for dominance" to account for variation. (See CM-1, initial, in Appendix G.) She was unclear on this point, explaining that "interbreeding" allows for dominance to arise in a population, and "that dominance lead[s] to evolution." (D 70) While one might understand her "interbreeding" as a version of in-breeding of a population, Stephanie's conception of interbreeding was more like the scientific conception of hybridization:
ST: Isn't there such a thing like selective breeding? Like if one species breeds with another one, then like all the good traits come out? I like that... Like if one species has something and the other one doesn’t and all the ones that have it breed together, eventually the ones that don’t, if they don’t breed enough, then they’ll sort of die out. (D 66)

Stephanie’s personal conception for the origin of variation signifies her use of an alternative conception of a species concept. This conception will be discussed in a later section.

Stephanie felt obligated to personally use a self-taught conception because she continually questioned the scientific explanations for the origin of variation:

ST: I don’t think the amoeba group could have evolved either. They don’t, they don’t have the traits to do that with. I don’t see how it could happen. (D 28)

Such questioning becomes understandable when we consider that Stephanie had a basic misunderstanding of the conceptions suggested by science. During the pretest, Stephanie offered the alternative conception of use/disuse as the origin of variation:

[In reference to the evolution of blindness in cave salamanders]  
ST: I said that because the salamanders live in complete darkness, light is not a necessity. After many generations of salamanders that became blind, the offspring were eventually born without sight.  
SD: Uh, uh. (Yes)  
ST: Ah actually, maybe that’s not right. Maybe the ones that originally went into the cave became blind and their offspring were born without sight and they became blind and maybe the process just happened quicker because they could function without sight... So maybe because they don’t use it, they lose it. (D 23)

However, this use/disuse explanation was tentatively suggested and within five minutes, she voiced her discomfort:

ST: I don’t know. [Pause] I guess they became blind just because the didn’t need their sight. But I don’t see how that could be passed on. (D 24)

So while the use/disuse explanation was offered by Stephanie she clearly recognized that it was not a plausible explanation.

Stephanie also suggested need as a source of variation:

[Written answer reference to the evolution of speed in cheetahs]
Gradually, the cheetahs developed stronger legs. Having food as an incentive, the cheetahs ran faster and gained stronger muscles in their legs that were passed on to their offspring. (Pretest #7)

However, in her oral comments given in the second week of the study, there was evidence of her discomfort with this explanation:

**ST:** I have a hard time forming opinions about this. I really don't think we can form something just because we need it. (D 15)

It is important to consider that although Stephanie did not find the conception of need as a plausible mechanism for the production of variation, she understood that to be the scientific explanation for this phenomena. At this point in the study, Stephanie did not have another conception to account for the origin of variation within the scientific explanation for evolution.

In an interview conducted two weeks later, there was evidence for conceptual change. In her concept map drawn to explain "how evolution works" Stephanie included mutation as a mechanism to account for the production of variation [CM-2, initial].

**ST:** (Reading her concept map) Development from one cell leads to mutation, or the possibility of mutation. Mutation requires necessity...

**SD:** Now what's the function of mutation on that side [of your concept map]?
**ST:** Okay, ah, maybe something developed, like an animal developed from one cell and then
**SD:** Uh, uh. (Yes)
**ST:** Mutated into something that could survive easier...
**SD:** Could you describe that a little bit?
**ST:** Right, okay, ahm if something mutates maybe it's because it needs to. For survival. (D 71)

By this point in the year, Stephanie had begun to explore mutation as the source of variation for the scientific explanation of evolution. However, as was just shown, the use of mutation was integrated with the pre-existing conception of need as the source of variation. With this integration, the source of variation and the actual action of natural selection has been joined (the selection pressure causes the production of the trait). The use of mutation makes this previously implausible explanation more
attractive, possibly because the introduction of mutation makes the explanation more mechanistic, and therefore more scientific.

It is clear that for both the scientific explanation and Stephanie's personal explanation for evolutionary change, variation in the original population is an important component. In her answer given during the interview, Stephanie explained that cheetahs evolved because:

**ST:** The ones that could run faster were the ones that were able to eat, and the ones that were slow maybe weren't able to catch as much food. (D 22)

While she was still forming conceptions of how that variation became present, Stephanie realized that to evolve a population must be variable. But I hesitate to call this a populational species concept, simply because Stephanie seems to have such a vague conception of a species. This was demonstrated by her personal explanation for the production of variation as relying upon hybridization between species. While Stephanie recognized the importance of variation, this variation was not linked specifically linked to a species concept. Stephanie's species concept will be discussed in more detail in a later section.

In Stephanie's explanation of the mechanism of evolution as expressed through a concept map, need was used as an essential component of evolutionary change. In both her scientific explanation and personal explanation, need served to link the origin of variation (either through mutation or "interbreeding") into the process of natural selection. Stephanie understood natural selection to be the most important component of the process of evolutionary change in both her personal explanation and her scientific explanation. Like Brian, Stephanie used the alternative conception of natural selection as:

**ST:** Well the ones that survive the best are the ones that are going to survive eventually. (D 22)
Stephanie understood natural selection as operating through the death of unfit individuals, instead of the more scientifically acceptable conception of natural selection as operating on differential reproduction within population.

Many of Stephanie's alternative conceptions about the mechanism of evolution applied to both her personal explanation and her understanding of the scientific explanation for evolutionary change. This intersection is demonstrated by Stephanie's conception of evolution as changes in the quality of a trait in an entire population, as opposed the more scientific conception of evolution being a gradual increase in the number of individuals in a population with a trait. Stephanie also used the alternative conception of biological fitness as "being able to change, to adapt to any changes." (D 21) This conception can be contrasted with the scientific understanding of fitness as having the greatest number of viable offspring.

The final aspect of Stephanie's understanding of the process of evolution was her lack of familiarity with geographic isolation as a means of providing for speciation:

ST: If humans were evolved from ah chimpanzees, then all the chimpanzees would have evolved into humans... So I think if this [a graphic of primate evolution] is right, then there would only be humans. (D 93)
ST: I just don't think that we evolved from fish. Because then there wouldn't be any fish. They would all be evolved. (D 26)

These comments signify that Stephanie was only familiar with vertical patterns of evolution. Such evolution occurs when one species changes over a great span of time so that the original species is much different from the most recent species. She had no conception of evolution as a speciation event caused by geographic isolation and resulting in reproductive isolation. Because her perplexity with branching patterns of evolution surfaced during several interviews, it is clear that this was an important issue for Stephanie as she approached scientific explanations of evolutionary change.
Human evolution.

The issue of human evolution was a very important aspect of Stephanie's conceptual ecology of evolution. When asked about her opinion of the theory of evolution, part of Stephanie's response was:

**ST:** I believe that man was created by God. There is a possibility that God created Neanderthal man and we evolved from them. I definitely do not think that my ancestry is from the mud. (D 25)

This response is not surprising when one considers Stephanie's conception of the patterns of evolutionary change. At this point in the semester, she understood the scientific conception of evolutionary change as a drive toward "being better"—something she interpreted as being human. For evolution to be a viable concept for Stephanie, it must explain human evolution.

Human evolution was Stephanie's testing ground for the theory of evolution, and it is not surprising that she gave this aspect of evolutionary thought much consideration. She studied anthropology a great deal when she was younger and this becomes evident as her first concept map is examined (CM-1, initial). While she understood the scientific conception of anthropology as including the evolution of man from an ancestral primate, Stephanie personally accepted an altered version of this explanation. (See Appendix G for CM-1, initial.)

Similar to the explanation for evolutionary change seen described in a previous section, Stephanie's personal conception of human evolution was that God created the initial prehistoric hominid, and this hominid underwent subtle evolutionary changes. This is an unusual stance for a self described "creationist." This is a case where an individual's theoretical commitments (interest in anthropology) allowed for changes within conceptions stemming from a belief system (evolution of humans).

Other conceptions of human evolution included Stephanie's understanding of humans as "related" to primates and other animals. During the interviews about instances (IAI-1, initial), Stephanie readily agreed that humans could be classified as
animals and as primates. However, it became evident that Stephanie had an alternative conception of what was implied by biological "relation."

Evolutionary relationships.

SD: Do you know what the term species means?
ST: Well it's just an order of classification. (D 88)
SD: What would be the purpose of classification? Why do we do that?
ST: To differentiate between animals? (D 117)

Stephanie used the term species and recognized that the evolving populations must be variable, but it is not clear if she used a conception of a species that could be applied to nature. Stephanie's conception of a species was a taxonomic group established by scientists in order to better study natural organisms. I could find no evidence that she tried to apply this taxonomic unit to nature or expected this unit to apply to nature. While biology teachers may find this to be a troubling alternative conception, this "artificial" species concept fits well with Stephanie's personal conception of evolution. Because she recognized only small changes within a species, she had no expectations that species would be "related" in the same manner as a biologist understands organisms are "related." Although Stephanie used the term "related" in reference to groups of animals, she meant that these groups, such as primates, had groups of similar characteristics. She did not understand this to mean that they shared some evolutionary ancestor. Stephanie did not recognize a species as being the sole taxonomic group capable of successful reproduction as evidenced by her use of "interbreeding" between groups (hybridization). Her conceptions in this area become more complex when we consider that Stephanie had an awareness that "real distantly" related species could not interbreed.

Evidence for evolution.

Despite the fact that Stephanie often referred to herself as a "creationist," she recognized the presence of strong evidence to support scientific evolutionary theory. Not surprisingly, the evidence of most importance to Stephanie came from anthropology:
ST: I believe evolution is a possibility because of all the evidence that supports the theory. Such as Lucy and finding the ancestral bones. (D 24)

Stephanie also explained how the species on the Galapagos islands could be considered to be evidence for evolution. If Stephanie used a constant scientific realist epistemology, based upon her wide prior knowledge I would expect her to react favorably to the theory of evolution. However, given her multi-disciplinary approach to epistemology and because this aspect of science clashed with a very important aspect of her life, religion, Stephanie was in the very unique position of recognizing the strengths of evolutionary theory while rejecting the "truthfulness" of it.

Historical aspects of evolutionary theory.

As discussed at the outset of Stephanie's description, her initial concept map contained some historical information. (See Appendix G for CM-1, initial). The inclusion of Darwin, the Galapagos islands, Origin of the Species, and the Leakey family signifies Stephanie's historical/sociological approach to the theory. It is difficult to establish if Stephanie used this historical/sociological approach to other biological topics, or if this approach was somehow unique to this theoretical framework. But as shown in the previous section, the orientation of her first map does not signify a lack of knowledge of the more process oriented aspect of the theory content of this theory.

Broad evolutionary theories.

When asked about her opinion concerning evolutionary theory on the pretest, part of Stephanie's response included:

ST: Some people say that you know, primordial soup and all that kind of stuff. I just don't see that happening. (D 25)

At this point in the year, Stephanie equated the theory of evolution with the formation of the original organism as well as all other changes that occurred within groups of organisms. But, as mention previously, her personal opinion of evolution included
only the very subtle changes that occur within groups of organisms. Stephanie understood that the act of formation of the original organisms to be dependent upon God. From a biological educators' perspective, it is unfortunate that Stephanie expected the scientific conception of evolution to account for original creation, as traditionally this field is considered to be outside the boundaries of evolutionary theory and within the realm of biochemistry. As such, this topic is seldom addressed in biology classes and it is poorly understood by even expert biologists. Because she expected evolutionary theory to make creation understandable in biological terms, she was continually disappointed.

It is not surprising to see that Stephanie did not understand evolutionary to be a major aspect of biology. Instead her vision of the important theories of biology were "anything that has to do with humans, just because that helps us directly." (D 148) Because of this expectation of biology, Stephanie failed to understand why the study of evolution is important in understanding all life forms.

**Natural history.**

Stephanie did not have a wealth of knowledge of historical or recent natural history. While she recognized the extreme age of the earth, she did not have a conception of the vast changes that have occurred during the course of geological history. She viewed the earth as a very old, but somewhat stable place. While she did display a deeper understanding of the natural history of dinosaurs and early humans, she failed to apply the knowledge of dinosaurs in many situations. However, issues of human descent were applied continually during our discussions.

**Other biological processes.**

Like Brian, Stephanie had a firm understanding of the genetic basis of physical characteristics. She answered the prediction interviews in a scientific manner which described the independent inheritance of the characteristics between generations. Also like Brian, she even had a sound knowledge of the action of sex-linked characteristics.
However, Stephanie's Mendelian conception of genetics can be contrasted with the more scientific view of the action of both blended and independently inherited traits.

Stephanie's firm framework for genetics was also demonstrated by her introduction of genetic terms into several interviews. In the first discussion of the sorting task (ST, initial), she explained that the rabbits' brown trait was recessive and the white was dominant at the outset. However, as the task progressed and number of brown rabbits increased in the population, Stephanie explained:

**ST:** But because the brown ones (rabbits) were surviving, they became dominant more and more.
**SD:** Uh, uh. When you say dominant, is that like a genetic kind of dominance or?
**ST:** Right. (D 76)

Based on this response, Stephanie used the alternative conception that ecological dominance is synonymous with genetic dominance.

Given her fundamentally sound usage of Mendelian genetics, her awareness that physical characteristics have a genetic basis, and her tendency to apply this knowledge, the early interviews with Stephanie become more confusing. When she discussed the evolution of webbed feet in ducks, Stephanie explained:

**ST:** Maybe because they [ducks] are not swimming at all, maybe their bones would form differently [without webbing] and that would be passed on. I don't think that after you are adult that you can alter it and then have it passed on.
**SD:** But maybe if it's a juvenile?
**ST:** Yeah, maybe. (D 18)

This almost Lamarckian explanation for the evolution of the trait of nonwebbed in ducks, is incongruent with the Stephanie's knowledge of genetics. This altered explanation, that traits acquired early in life can be passed on, is not unique to Stephanie and has been documented in high school students in other studies (Cough & Wood-Robinson, 1985a). But why Stephanie would offer this explanation is an important question. It suggests that she did not fully apply her knowledge of genetics to a question that has to do with evolution.
Stephanie was remarkably anti-anthropomorphic in her answers to interview questions, as shown in her explanation, "I don't think mosquitoes learn anything." This rejection of anthropomorphism implies a certain biological sophistication that was absent from many other students in the class.

Like Brian, Stephanie had a functional knowledge of animal taxonomy. She could categorize organisms shown during the interviews about instances (IAI-1, initial) and explain her reasoning behind this categorization. But, unlike Brian, Stephanie did not recognize taxonomic relationships as reflecting evolutionary relationships.

See Figure 13 for a summary of Stephanie's initial conceptual framework for evolution.

Mid-year framework

**Mechanism.**

The most substantial changes occurring between initial to mid-year interviews were found in the conceptions that describe the mechanism of evolutionary change. Stephanie's concept map (CM-3, mid-year) and her explanation of the sorting task (ST, mid-year) demonstrate that she was capable of using several scientific conceptions of process.

**ST:** [Reading her concept map] Evolution is caused by mutation, which created change in the population, through natural selection which is a theory of Darwin, which is survival of the fittest. Darwin coined that, where desired traits are passed on. (D 217)

(See Appendix G for CM-3, mid-year.)

Stephanie's conceptions about the origin of variation underwent the greatest amount of change. As described previously, by the end of the initial interviews, Stephanie had tentatively proposed mutations as the source of variation. By mid-year, this conception had become more deeply embedded as demonstrated by her explanation that evolution "is caused by mutation." (D 217) "I think it's {evolution} all mutation." (D 186) However, her understanding of mutation was not completely scientific. Early in the mid-year interviews, she used a conception of mutation that was inextricably linked to need:
### Human Evolution
- Humans are animals
- Humans are primates
- Humans are product "primordial soup" and subsequent drastic evolution (R)
- **Humans as product of separate creation and subsequent subtle evolution**

### Characteristics of Evolutionary Changes
- Evolution includes drastic changes between groups (R)
- Evolutionary changes are predictable and reproducible (R)
- Evolution as progression to superior organisms
- **Evolution includes small, gradual changes within a group**

### Broad Evolutionary Theories
- Evolution includes creation of first life and subsequent changes (R)
- Evolution includes only small changes within a group
- Evolution unimportant in biology

### Evidence for Evolution
- Anthropological fossils
- **Biblical evidence is refuting evidence**

### Evolutionary Relationships
- Species is as taxonomic group
- Relation describes physical similarities

### Related Biological Knowledge
- Mendelian genetics
- Rejection of anthropomorphism
- Genetic inheritance as a random process operating within constraints

### Mechanism
- **Variation stems from interbreeding for dominance**
- Variation stems from a need (R)
- Tentative recognition of mutation as source of variation
- Evolving populations are variable
- Natural selection works through death of unfit individuals
- Evolution is a series of vertical changes in a population

### Historical Aspects of Theory
- Darwin's writings
- Leakeys and anthropology

### Natural History
- Old, relatively stable earth
- Limited knowledge of historical or biology
- Knowledge of animal taxonomy

---

**Note. Italics indicate instances of conceptual change.
Shaded block indicates conception based on belief.
Solid block indicates academic conception.
(R) indicates rejection of conception.**

---

**Figure 13**
Summary of Stephanie's initial conceptual framework for evolution

**ST:** It just seems that all the evolutionary changes take place because there was a need for it. I just don't think we grow something for nothing. (D 186)

Just three weeks later during an interview with the bear mutation graphic (PI-1), Stephanie began to recognize mutations as a being a random force in evolutionary process:
ST: Well mutations doesn't [sic] just happen because you want it too. It just sort of happens. . . And so it it's, if it's beneficial, it's gonna' survive and help the species. If it's not, that one's going to die out real quick and not reproduce. (D 226)

This represents a massive change from her initial conceptions. Not only did mutations represent a scientific conception of the origin of variation, but her recognition of their random aspect served to fundamentally restructure her understanding of the nature of evolutionary changes. However, the acceptance of the random aspect was not wholesale, as shown by Stephanie's recognition of the beneficial components of most mutations. This conception becomes even more complex as we consider that while Stephanie recognized most mutations as being beneficial, she realized that their external cause was random, "they just happen." (D 219) Even with the tentative introduction of the random aspect to evolution, at this point Stephanie had no conception for genetic drift as a mechanism of evolutionary change.

It is important to note that the conceptual change toward a scientific usage of mutation initially began with a link to Stephanie's prior existing conception of need as a component of evolutionary change.

By mid-year, Stephanie completely isolated the origin of variation from the action of natural selection. (See CM-1, mid-year, in Appendix G.) She used the scientific conception of natural selection as operating on the variation already present in a population of organisms. However, Stephanie continued to understand that natural selection operates through the death of unfit individuals.

Nature of evolutionary changes.

Stephanie retained the use of many of her initial conceptions about the nature of evolutionary changes. While Stephanie understood perfection in terms of human characteristics, interviews conducted at mid-year revealed her understanding of success for a species. She explained that a successful species was one that "survived a long time." (D 167) Curiously, she defined failure of a species to include extinction
without "giving rise to something else." (D 169) She used this conception when
discussing dinosaurs, explaining that dinosaurs did not fail, because "they say birds
evolved from them. They just sort of changed." (D 169) This comment is an
important one. It signifies a broadening in the scope of Stephanie's personal
conception of evolutionary change.

Previously, Stephanie rejected the drastic changes she understood to be described
by scientific evolutionary theory. Formally, she continued to reject this conception
during the mid-year period. However, she continued to explain that her personal
understanding of evolution included gradual, subtle changes within a group. This was
more that just a rote answer as demonstrated by the graphics Stephanie selected in an
interview about instances (IAI-3, mid-year). When asked to pick the graphic which
best depicted her understanding of evolutionary change, Stephanie selected graphics
that depicted subtle changes within similar organisms. (See graphics 9A and 9D in
Appendix C-2). However, her dinosaur comment indicates a change in what
Stephanie understood to be a "subtle change" and "within a group." Stephanie's
conception of their terms expanded so that she could use and apply the various theories
of dinosaur evolution.

ST: I think maybe crocodiles came from dinosaurs and birds maybe
came from dinosaurs. I mean, I can kinda' see the connection there.
But I can't see a connection between bacteria and an elephant. (D 182)

In an interview two weeks later, Stephanie began to incorporate this change in her
formal description of evolutionary change:

ST: I guess it [evolutionary change] could be drastic over time if you
compare the changes between something over 10 million years ago and
something today. That's a big, drastic change.
SD: Uh, uh. (Yes)
ST: And over a couple of years, there's not drastic change. (D 223)

Stephanie retained use of the conception of evolutionary changes as being
predictable, but there are signs that this conception was also undergoing modest
changes during the mid-year period. In a prediction question, Stephanie explained that
if conditions were constant, a scientist could accurately predict the outcome of an
evolutionary event. However, in the same interview Stephanie explained:

\[\text{ST: I'd definitely go with random [as being a characteristic of}
\]
\[\text{evolution].}
\]
\[\text{SD: Random? Why?}
\]
\[\text{ST: Because mutations are random. I think it just affects certain ones,}
\]
\[\text{just kinda' random. That's also change, it's kind the same thing. . . . Ah,}
\]
\[\text{I don't think there's a real order to it either. I think it's just a way things}
\]
\[\text{happen. (D 223)}
\]

Logically, Stephanie's conception of evolutionary changes as being predictable and
random are incompatible, but each conception was not only explained by Stephanie but
also applied in interview situations.

The final conceptual change which occurred for this group of conceptions was
seen in Stephanie's conception of adaptations. During the interviews conducted for the
mid-year conceptual framework, she began to recognize the difference between learned
(proximal) adaptations and genetic (ultimate) adaptations. In response to the bear
graphic concerning possible mutations (PI-1, mid-year), Stephanie explained that
adaptation of burrowing was learned:

\[\text{ST: I don't think something in his [the bear's] chemistry mutates and}
\]
\[\text{makes him do that [burrow].}
\]
\[\text{SD: All right, so?}
\]
\[\text{ST: That's just a behavioral adaptation. (D 225)}
\]

Natural history.

Stephanie's conceptions of natural history demonstrate the nature of the interface
between her scientific knowledge and knowledge based upon belief. When asked to
graphically depict the "time line of life on earth," Stephanie explained that the earth
was 4.5 million or billion years old, "but I don't know if it really makes a difference.
It's hard for me to distinguish." (D 179) The only other occurrences she depicted
were the existence of dinosaurs, the extinction of dinosaurs, and the creation of
humans. Stephanie's comment, "And that's all you want, just life on earth?" signifies
that she understood these three events to be the only noteworthy historic biological
occurrences. We then discussed her graphic:
SD: What do you think went on in that big hole [between creation of the earth and dinosaurs]?

ST: Oh, all the scientist say it was all that primordial soup mess. And all like that. And we were formed by a bunch of chemical and little cells coming out of the sea.

SD: Uh, uh. (Yes)... So what would you say. What do you think happened?...

ST: It's hard to say.

SD: Uh, uh. (Yes)

ST: I mean, because we weren't there. And there's no real guarantee to find out.

SD: Uh, uh. (Yes) Uh, but if you had to lay money on it?

ST: But, but judging from the dating of the dinosaur skeletons and the estimation of when the earth started, I guess that would be about true.

SD: Yeah?

ST: But we might have an error in finding out the dates.

SD: Uh, uh. (Yes)

ST: I, I think it's probably true. I go with it.

SD: Uh, uh. (Yes)

ST: Until something else disproves me. (D 180)

Stephanie was beginning to view more favorably the scientific explanation of the origin of biological organisms. However, based upon the nature of her responses, this remained an abstract and tentative acceptance. Minutes after this conversation, Stephanie explained:

ST: Ahm, I sort of think that with evolution and all I think that maybe ahm, man was created like how anthropologist say in Homo erectus, in walking on all fours.

SD: Uh, uh. (Yes)

ST: And then evolution took place from there. But I don't think that everything started with one cell. (D 181)

Stephanie rejected her tentative exploration of a scientific explanation of the origin of life. This rejection took the form of a common pattern. Because humans were the product of a theistic creation, life could not arise in the manner described by science.

Stephanie's conception of the age of the earth illustrates again the interface between scientific knowledge and knowledge based on belief:

SD: How old do you think the earth is?

ST: Oh, I've heard so many different things in books I can't remember.

SD: Uh, uh. (Yes)

ST: I think somebody said 4 billion, and then according to the bible it's only like, I don't know, like 5, 6, or 10 thousand, something like that.

SD: Uh, uh. (Yes)

ST: I can't really remember.
**SD:** So if you
**ST:** I'd say closer to the 4 billion.
**SD:** Uh, uh. (Yes) Why, why, why would you say closer to 4 billion?
**ST:** I think it's 4 million, I don't remember.
**SD:** Why would you
**ST:** Just because ah, it just seems like well the dinosaur excavations and stuff. It just seems a lot older. (D 164)

Stephanie understood the earth to be extremely old because she accepted the past existence of dinosaurs. This relationship is more illustrative when it is compared to its logical counterpoint. Logically, the one might say the earth is old, therefore dinosaurs have existed. Instead, the biological information (dinosaurs) is more influential (more authentic) to Stephanie than the physical information of the extreme age of the earth.

The relative weight Stephanie attributes to biological and physical evidence may be an artifact of the complex interface between scientific accounts of evolution and her own personal understanding, or this may be a common occurrence.

Also illustrated by the previous quote is Stephanie's inability to distinguish between billion and millions. This failure has been documented in other students in a study by Renner et al. (1981). It is a relatively common situation for a student to be unable to recognize the vastness represented by such time scales. As explained by Dawkins (1986), this inability may be a large factor in Stephanie's failure to completely understand the generation of vast biological diversity through the process of evolution.

**Broad evolutionary theories.**

Stephanie's use of the broad scientific theories of evolution increased during the mid-year interviews. She began to recognize her personal conception of gradual, subtle evolution in terms of Darwin's gradualism. She lumped her conceptions of the scientific explanation of drastic evolutionary changes with saltation - an idea she still fundamentally rejected as implausible. While she included the theory of punctuated equilibrium in her concept map constructed in response to "map your understanding of evolution," Stephanie could never explain what was meant by this term, simply stating that it contrasted gradualism (CM-2, mid-year).
Other biological knowledge.

Within her conceptual framework for genetics, Stephanie began to use a conception of genetic inheritance as being a combination of randomness and constraints, what she referred to as a "random pattern." This relatively sophisticated understanding of inheritance signifies a further embedding of the conception of randomness into Stephanie's understanding of broad biological processes - a change that also occurred within her conceptual framework of evolution.

Other conceptual groups.

The other groups of conceptions, including the evidence of evolution, the historical aspects of evolutionary theory, and human evolution, underwent no obvious changes from the initial framework. Stephanie's understanding of evolutionary relationships also remained relatively stable except for her inclusion of possible dinosaur phylogenetic relationships. This assortment of theories concerning dinosaur lineage continued to surface in Stephanie's interviews, and she used these theories to illustrate many of her comments.

Belief system.

Despite the many changes which occurred in Stephanie's conceptual framework for evolution, her self-characterization remained stable. For a homework assignment completed during this period, Stephanie referred to herself as a "creationist." (Artifact 4) Stephanie recognized the uniqueness of her situation in her comments on a concept map she constructed:

ST: I say some things that are contradictory. Because we have facts in this area [evolution], then it kind of refutes this theory or idea [creationism]. Ahm, it's kind of weird to have all my theories or ideas on this side [toward evolution], when actually I believe this side [toward creation]. . . . I'm kind of a combination of both. (D 215-216)

The considerable conceptual change described for this period occurred without a wholesale change in belief structure. This section provides evidence that academic conceptual change may occur without a corresponding change in belief.
See Figure 14 for a summary of Stephanie's mid-year conceptual framework for evolution.

Year-end framework

The most prominent components of Stephanie's year-end conceptual framework for evolution can be found in the concept map she drew in response to the request, "map your understanding of evolution." [See Appendix G for Stephanie's concept map (CM-1, year-end).] This map demonstrates that while Stephanie could apply a scientific conception for the mechanism of evolution, she still found the historical aspects of the theory to be of importance.

Mechanism.

Conceptions of the mechanism of evolutionary change underwent the greatest degree of conceptual change. By the end of the year, Stephanie was capable of using a very scientifically acceptable explanation of the process of evolutionary change:

**ST:** [Writing in reference to the evolution of speed in cheetahs] A mutation occurred that allowed a [cheetah] to run faster, and this trait was passed on. Since these animals could run faster than others, they were able to catch more prey, mates, etc. [Posttest #7]

In this answer there is evidence for conceptions of (a) mutation as the source of variation, (b) the importance of variation, (c) the action of natural selection. While many of these conceptions were present during the mid-year period, conceptual change did continue to occur during this period. The most influential of these changes was Stephanie's recognition of mutation as a fundamentally random process.

**SD:** [In reference to the bear mutation graphic] Which one of them [mutations] is more likely to happen?

**ST:** I think all of them is [sic] equally as likely to happen.

**SD:** All of them, why?

**ST:** Because it's a mutation, it's random! (Her emphasis) . . . So, I mean, a mutation doesn't think about what it's going to do.

**SD:** Uh, uh. (Yes)

**ST:** It just sort of happens. So any of these could happen. (D 269)

One of the conceptions that was used by Stephanie initially, her understanding that variation originated from "interbreeding for dominance," was not used in the
<table>
<thead>
<tr>
<th>Human Evolution</th>
<th>Characteristics of Evolutionary Changes</th>
<th>Broad Evolutionary Theories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humans are animals*</td>
<td>Evolution includes drastic changes between groups (R)*</td>
<td>Evolution includes creation of first life and subsequent changes (R)*</td>
</tr>
<tr>
<td>Humans are primates*</td>
<td>Evolution includes small, gradual changes within a group*</td>
<td>Evolution unimportant in biology*</td>
</tr>
<tr>
<td>Humans are product “primordial soup” and subsequent drastic evolution (R)*</td>
<td>Evolution as progression toward superior organisms*</td>
<td>Gradualism</td>
</tr>
<tr>
<td>Humans are product of separate creation and subsequent subtle evolution*</td>
<td>Evolutionary changes are predictable and reproducible (R)*</td>
<td></td>
</tr>
<tr>
<td>Evidence for Evolution</td>
<td>Evolutionary changes are random in their origin</td>
<td></td>
</tr>
<tr>
<td>Anthropological fossils*</td>
<td>Two meanings attributed to biological adaptations</td>
<td></td>
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<tr>
<td>Biblical evidence is refuting evidence*</td>
<td>Evolutionary Relationships</td>
<td>Historical Aspects of Theory</td>
</tr>
<tr>
<td>Related Biological Knowledge</td>
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<td>Leakeys and anthropology*</td>
</tr>
<tr>
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<td>Relation describes physical similarities*</td>
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<tr>
<td>Rejection of anthropomorphism*</td>
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<td></td>
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<tr>
<td>Genetic inheritance as a random process operating within constraints</td>
<td>Mechanism</td>
<td>Natural History</td>
</tr>
<tr>
<td>Variation stems from interbreeding for dominance*</td>
<td>Mutation is source of variation</td>
<td>Old, changing earth</td>
</tr>
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<td>Evolving populations are variable*</td>
<td>Natural selection works through death of unfit individuals*</td>
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</table>

Note. Italics indicate instances of conceptual change.
* indicates retention of conception from previous description.
Shaded block indicates conceptions based on belief.
Solid block indicates academic conception.
(R) indicates rejection of conception.

Figure 14
Summary of Stephanie’s mid-year conceptual framework for evolution
posttest interview period. This conception was replaced by the scientific conception of mutation as the origin of variation.

Despite the conceptual change described above, there was still no evidence of Stephanie's recognition of the action of genetic drift by year-end. On the posttest exam question that would have the highest probability of eliciting a conception of genetic drift, Stephanie gave a vague and uninformative answer:

**ST:** [Writing in reference to the evolution of blindness in cave salamanders] I guess through a mutation in one salamander that may have caused lesser sight that evolved to blindness in several generations. (Posttest #8)

Stephanie understood that all changes that become established as a means of fulfilling the population's need. She had no conception of evolutionary changes that could become established by chance.

As suggested by the omission of neutralist change, need continued to be a component of Stephanie's understanding of process. However, by the end of the year she had completely detached the need for a variation from the process responsible for the origin of variation:

[In response the the sorting task]

**SD:** Would the mutation have happened without the hawk showing up?
**ST:** Yeah.
**SD:** Okay.
**ST:** It would have happened regardless. Well, see I think it's like, it happens and then it's needed.
**SD:** Yeah?
**ST:** Rather than it's needed and it happens. (D 272)

During the last interview, there was evidence that Stephanie did not have a conception of the pattern of horizontal evolutionary changes or the process that might be responsible for these changes:

**ST:** I don't really see how people came from monkeys.
**SD:** Uh, uh. (Yes)
**ST:** Because I don't think there would be any monkeys left.
**SD:** Okay.
**ST:** It just seems like when something adapts, then the weaker thing that it adapted from dies out and gets replaced. . . I mean, it's like, if an animal is improved, if it evolved into something to help it out. (D 294)
While she recognized that the scientific community discussed such changes, she could not understand the mechanisms through which such evolution could come about. The form of evolution personally accepted and explained by Stephanie continued to be subtle, vertical changes within a group.

The posttest exam also identified another alternative conception. Stephanie explained that an evolutionary change within a population of ducks would result in most of the population having a little more webbing than their parents but other ducks having the same amount of webbing. This is an alternative conception not previously described in the literature. While Stephanie acknowledged that evolutionary changes involve an increase in the proportion of the population with a trait, she also recognized that the quality of this trait gradually increases in the population.

Nature of evolutionary changes.

The following passage from Stephanie’s posttest exam sums up much of her personal understanding of evolutionary change:

ST: I believe that evolution occurs in small beneficial doses to help a species survive, such as the DDT and the mosquitoes, but I am still not convinced that humans evolved from one-celled organisms that evolved out of the sea. I’m still a creationist, but I also believe that small changes that occur in a species through mutation helps that species to "evolve and survive." (Posttest #9)

Conceptions shown in this answer include:

(a) her personal understanding of evolution to include small, subtle changes within a species,

(b) evolutionary changes in a species are beneficial, thus the random aspect of evolutionary changes were not included,

(c) that the scientific explanation for evolution describes vast changes within human lineage

Of these three conceptions, the one that may be the most misleading is Stephanie's personal understanding of evolution to include small, subtle changes within a species. Her use of this formal statement remained constant throughout the scope of the study,
but the conception it represented underwent many changes. By small changes, Stephanie meant over a short period of time a species would undergo very subtle changes. These changes may be accretionary over a long period of time. The phrase, within a species, is misleading. (Her use of species has changed over the year, initially she used group.) As described in the mid-year framework, Stephanie understood her personal explanation for evolution to be congruent with the scientific conception of dinosaurs giving rise to birds, and the vertical changes within hominid lineages. But she understood these changes to initially occur within a group.

The final change seen in Stephanie's conception of the nature of evolutionary changes was seen in her understanding of adaptation. Stephanie explained that "chill bumps" were not a form of adaptation. Instead, she explained, "I was thinking more of a larger scale adaptation" with a genetic basis. (D 248) Her understanding of an adaptation at year end included only evolutionary adaptations, and not the proximal changes which occur within an individual organism in response to sudden environmental change.

**Natural history.**

There were few changes in Stephanie's understanding of natural history during the year-end period. However, another feature revealed in this period was Stephanie's conception of the natural world as being fundamentally competitive:

**SD:** When you think about nature, do you think of it as being very competitive?

**ST:** Yes. Ah, like the survival of the fittest and the food chain and that kind of thing, all competing to live.

**SD:** What are things competing for? What do organisms compete for?

**ST:** Compete for food. Ah, they compete for mates. Every thing that it necessary to live, they compete for. (D 267)

As was mentioned with Brian, this conception is an essential one for a construction of a scientific understanding of evolution through natural selection.
Broad evolutionary theories.

Stephanie's understanding of the scope of scientific evolutionary theory remained unchanged during the study. She understood evolutionary theory to include both the origin of life and the changes which occurred within organisms after that creation.

However, her use of other broad theories changed after the mid-year period. During the mid-year period, Stephanie compared theories of punctuated equilibrium and gradualism, and characterized her own personal views as being more congruent with gradualism. But during the interviews at the end of the year Stephanie explained, "I just remember the details of [those theories]. I don't feel comfortable enough putting them down." (D 274) Even after those theories were explored and applied by Stephanie, she did not continue to use them. These theories did not become a part of her conceptual framework for evolution.

Previously, Stephanie did not understand evolutionary theory to be an important aspect of biology. However, on her final exam, Stephanie voiced a different conception:

**ST:** There are three extremely important concepts that I think are critical in biology: evolution, the study of DNA and genetic engineering, and the discussion of scientific ethics. Evolution is important because students should be taught the theories of where they came from and how they came to be the way they are. It gives a strong, firm basis of comparing animals to one another and demonstrates that nature is dynamic, not static. Evolution gives the student food for thought, and it is easily discussed in combination w/other ideas, such as zoology, anthropology, archeology, and even geology. It encompasses several scientific ideas. (Artifact 7)

This passage signifies that Stephanie understood evolutionary theory to play an important role in synthesizing several areas of scientific knowledge. Because this answer was given in response to an exam question, there is the strong possibility that Stephanie was expressing her understanding of scientific knowledge, and not the understanding that she personally accepted and used. But this answer demonstrates that Stephanie did recognize the broad academic importance of evolutionary theory.
Other conceptual groups.

The other aspects of a conceptual framework for evolution underwent no substantial changes over the year-end period. Her recognition of the evidence for evolution, her stress of the historical aspects of evolutionary theory, and other aspects of related biological knowledge were retained.

Belief system.

ST: [Written in response to question about her "opinion of the theory of the evolution"] I still believe in Creationism, however, I also agree w/evolution to the degree that an animals' mutated traits that is [sic] a benefit to the animal will aid its survival and be passed on to offspring and allow it to dominate the population though survival of the fittest. I still do not agree w/the notion that man crawled out of the sea millions of years ago as an amoeba. I think God created man, and man then evolved to his present state. (Second posttest answer #9)

While several aspects of her conceptual framework for biology are represented in this answer, this quote also speaks to Stephanie's beliefs of evolution. This belief remained constant throughout the course. She continued to reject what she perceived as the scientific explanation of the origin of life and of biological diversity. Instead, she used a progressive creationist understanding by viewing major groups to be a result of special creation and acted on by a progressive form of evolution. Also reflected in this quote, Stephanie's belief structure remained oriented around her understanding of human evolution.

See Figure 15 for a summary of Stephanie's year end conceptual framework for evolution.

Summary of year long conceptual change

A noteworthy feature of Stephanie's conceptual framework for evolution was her recognition of the conflict between scientific knowledge and knowledge based on a belief framework. Stephanie was very concerned with the actuality of evolution and its implications for the other aspects of her life. During the scope of this study, Stephanie underwent considerable conceptual change in evolution without a corresponding magnitude of change in her belief structure. Minor aspects of her belief framework
### Human Evolution
- Humans are animals
- Humans are primates
- Humans are product of “primordial soup” and subsequent drastic evolution (R)
- Humans are product of separate creation and subsequent subtle evolution

### Evidence for Evolution
- Anthropological fossils
- Biblical evidence is refuting evidence

### Related Biological Knowledge
- Mendelian genetics
- Rejection of anthropomorphism
- Genetic inheritance as a random process operating within constraints

### Characteristics of Evolutionary Changes
- Evolution includes drastic changes between groups (R)
- Evolution includes small, gradual changes within a group
- Evolution is progression toward superior organisms
- Evolutionary changes are predictable and reproducible (R)

### Mechanism
- Mutation as source of variation
- Recognition of harmful mutations: Mutations are random
- Evolving populations are variable
- Natural selection works through death of unfit individuals
- Evolution as a series of vertical changes in a population
- Evolution includes an increase in the quality of a trait

### Broad Evolutionary Theories
- Evolution includes creation of first life and subsequent changes (R)
- Evolution includes only small changes within a group
- Evolution unimportant in biology

### Historical Aspects of Theory
- Darwin’s writings
- Leakeys and anthropology

### Natural History
- Old, changing earth
- Limited knowledge of historical or recent natural history
- Knowledge of animal taxonomy
- Nature is competitive

### Evolutionary Relationships
- Species is a taxonomic group
- Relation describes physical similarities
- Dinosaurs gave rise to birds and crocodiles

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**Note.** Italics indicate instances of conceptual change.

* indicates retention of conception from previous description.

Shaded block indicates conceptions based on belief.

Solid block indicates academic conception.

(R) indicates rejection of conception.

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**Figure 15**
Summary of Stephanie’s year-end conceptual framework for evolution
altered allowing for large scale academic conceptual change. In this regard, Stephanie may be unique. While Stephanie would be considered to be a progressive creationist, she also used a multi-disciplinary approach to science. This approach allowed her to recognize the attributes of evolutionary theory apart from her perception of its flaws. As a result of her consideration of the theory, while she continued to personally reject the theory, she began to incorporate many aspects of this theory into her own personal understanding of subtle evolutionary change.

Tyler: Biologist as Authority Seeker

Tyler, a senior girl, was one of the original interview participants. This selection was based on her use of several alternative conceptions about the process of evolution as well as her perception of a conflict between scientific knowledge and religious beliefs. Like Stephanie, interviews with Tyler presented an ideal opportunity to study the interface between scientific and religious knowledge.

Tyler was a small, athletic, friendly girl who laughed quickly in all conversations. Like Stephanie and Brian, Tyler's interview behaviors were much different than her classroom behaviors. During interviews, Tyler was talkative and speculative, and she followed any tangential topic that arose in conversation. Our talks were comfortable, and often she completed my statements or questions. But in class discussions Tyler seldom spoke unless called on. I have only three recorded instances in which Tyler volunteered an answer in class. Tyler explained that while she was engaged during class discussions, she did not enjoy the competitive nature of whole class participation. However, this classroom behavior differed when she was in small group situations. Here she spoke readily, gave directions to her group mates, and often approached the teacher with questions.

In our interviews, Tyler often compartmentalized her knowledge; she did not commonly attempt to relate different frames of reference. But this process of compartmentalization broke down in our interviews as she began to compare her
personal and biological knowledge. Such comparisons continually resulted in personal confusion for Tyler. The following passages demonstrates an instance in which Tyler began to synthesize different forms of knowledge about the age, origin of the earth, and early natural history. Also prominent in this passage is confusion resulting from this synthesis.

SD: How long ago do you think that was [since the existence of dinosaurs]?
T: I should know that.
SD: Oh no, not necessarily.
T: Oh gosh! I'm sure I've been told and I've read books... .
SD: Ohm, how long do you think it was between when the earth was first created and then the
T: and then dinosaurs?
SD: Yeah.
T: I think it's probably like [pause] probably like half a million years or something.
SD: So like a half a million years? Could you like draw that on a line or something? . . .
T: Okay, I want to. Ahm, [pause] and I think there were, I think there were bird kinda' dinosaurs.
SD: Okay.
T: [Looking at her drawing] Okay, that's not an airplane, that is a bird. Ahm. And then dinosaurs pretty much died.
SD: Okay. Make or you can put that on another piece of paper, put dinosaurs died. Died. Okay.
T: Okay. And then I think it's like and now it gets confusing. [Laughs] I guess, see what I'm thinking of right now is the ah like what I've learned like in church.
SD: Uh, uh. (Yes)
T: and what I've learned in biology. . . . I don't know. . . . I would tell you that. [Long pause] I don't know what came before man except there were dinosaurs and then I know man was created by God and stuff
SD: Uh, uh. (Yes)
T: That's what I've always thought in my heart. . . . I would say God created us.
SD: Okay.
T: [Laughs] Uh, uh. (Yes) Because I don't know about all this other stuff.
SD: Uh, uh. (Yes)
T: That's just what I've always felt that God put Adam and Eve on this earth
SD: Uh, uh. (Yes)
T: and then from there, all of us.
SD: So all right, where would Adam and Eve come in relation to dinosaurs?
T: Well they're way after them.
SD: Okay. Put a big line.
T: But I don't know about all the evolution stuff now.
SD: Uh, uh. (Yes)
T: I just don't know what, what to think. I don't know what to put. If there were other creatures
SD: After the dinosaurs?
T: I'm sure there were . . .
SD: Uh, uh. (Yes) Now so how did those other creatures, you know so how did the dinosaurs
T: Come about?
SD: Yeah. And all those other creatures.
(Long pause)
T: Golly! Well, when I think about, man was the first creature created by God, so I don't know where they came from. [Laughs]
SD: Uh, uh. (Yes)
T: They don't just form.
SD: Uh, uh. (Yes)
T: Oh Goah! I need to get things straight, don't I? [Small laugh]
SD: Well, no, you know. This is the time you're working things out. So . . . man was the first creature created by God, that's from the Bible?
T: That's well yeah, that's what I've always thought.
SD: Uh, uh. (Yes)
T: I guess I never even thought about where dinosaurs came from. It didn't cross my mind.
SD: 'Cause you don't think about dinosaurs in church?
T: No, that's true.
SD: And you don't think about Church when you're in science class?
T: [Shakes her head yes]
SD: Or looking over a book.
[Both laugh]
T: Do you understand what I mean?
SD: Yes, I know. You've never had to put those two kind of different ways of thinking together.
T: Together. Exactly.
SD: Do you think they should go together?
T: Yeah. ( . . . ) I do, they, there has to be some kind of explanation for them to fit together.
SD: Uh, uh. (Yes) [Pause]
T: [Whispers] I don't know. (C 171-175)

Tyler explained one cause of her confusion when considering evolutionary theory:

T: No one's ever asked me what I thought. I was just taught about that no matter what I thought was right. [Small laugh] But I don't know. (C 87)

It seems that she had never attempted to integrate her differing conceptions because this was not expected of her.

Tyler's approached biology as an authority seeker. When confused, she would rely on knowledge already constructed by an outside authority (i.e., texts, the researcher) rather than attempt to resolve the conflict on her own. After one mapping
session on the process of evolution, Tyler became aware both of her lack of knowledge and the conflicts between her religious and scientific knowledge and commented, "I'd wish I'd like read something on evolution. I'm sorry." (C 71) After one interview in which she discussed her confusion about the difference between her scientific and religious knowledge, she asked:

T: Can I ask you something?
SD: Yeah.
T: Do you know the answers to all these questions?
SD: Well, you know, there's no
T: Does anybody? (C 177)

Like the students described by Lawson and Weser (1990), Tyler was easily swayed by external opinions and less assured of her own abilities to construct a solution.

Tyler hoped to become a physical therapist, and this is the reason she enrolled in the Biology II course. She chose this profession because of her interest in the human body. Tyler explained that her favorite academic subject was science, because she enjoyed learning about anatomy and physiology. She exercised on a daily basis, playing tennis, running on the track team, and working out at a health club.

Other than exercise, Tyler's main activities centered on school work and pleasure reading. While she applied herself, Tyler had a pragmatic approach to school work, "I'll do what I can." (C 3) Given any free time, Tyler exercised frequently and read fiction, explaining, "I like real life, good books." (C 5) Tyler got little enjoyment from school based reading, and English was one of her least favorite subjects.

Despite her friendly, easy going demeanor, Tyler's mother characterized her as being independent and competitive. I think of Tyler as more mature than her classmates in that (a) she could examine U High in a manner in which few of classmates could, (b) she had firm professional goals, and (c) her approach to school was designed to achieve those goals. It is evident to me that Tyler's approach to the discipline of biology did not characterize all aspects of her academic or personal life.
Tyler's Conceptual Ecology

The most influential aspect of Tyler's conceptual ecology was her orientation toward science. While Tyler was interested in science, she was most interested in its medical aspects:

T: I love to learn about the body and stuff. If I could do anything, I would just learn more about humans.... What they're made of and how diseases, and just how they work. (C 37)

At the outset of the study, Tyler viewed biology as the "study of the human body" but this conception broadened during the course of the study. The remainder of science, and specifically biology, held less of Tyler's interest. This was reflected in Tyler's scant knowledge of biological organisms. In the interview about instances (IAI-1, initial), Tyler had no knowledge of the function of flowers in angiosperms:

SD: Ahm, do you know that function of flowers for the plant?...
T: I sure don't. I never even thought about it (a flower) doing anything for the plant.... Honestly, I've always just thought flowers are there because they're pretty.... That may sound real stupid but I've never thought about a flower having a function. (C 104)

At the outset of the study, while Tyler was more mechanistic in her approach to physiology, she had a largely aesthetic view of the natural world (Cobern, 1993). She did not view biological organisms in terms of cause and effect but in terms of aesthetics qualities such as beauty, order, and symmetry. Tyler was capable of mechanist thought, but this was not her first approach to making sense of the natural world. Many of Tyler's conceptions of nature changed during the course of the study, and these changes will be addressed in later sections.

Tyler understood there to be distinctions between the operations of natural world and the world of humans. For humans:

T: I think that things happen because they're meant to happen. And I think that no matter what happens, everything, like, no matter what happens to me, everything is going to turn out fine.... I'm talking just like with humans. With people. (C 70)
But for the "natural world things are more scientific." (C 70) Clearly, this aspect of Tyler's view of the human/natural world has close ties to her religious belief framework.

Like Brian and Stephanie, Tyler was a realist, and she understood science as an attempt to "talk about what happens in the world." (C 33) But hers was a contextual realism, as she explained:

T: It's [science] a bunch of knowledge that's all linked together somehow, but it's also a process of learning. 'Cause there's never an end in science. There's never a final answer. You can always discover something new or take a new aspect of it. (C 33)

This conception of science is contrasted with Tyler's conception of scientific theories and facts. She acknowledged that theories are "just an idea that somebody gets," a conception that describes theories as tentative but also makes them equivalent to a scientific hypothesis. But Tyler understood scientific facts to be a reflection of reality:

SD: Okay, which one has higher standing? You know, what we should value? A theory or a fact?
T: Ah, probably a fact.
SD: Why?
T: Because they're true.
SD: Okay, so theories aren't true?
T: Not that they can't be, they might be.
SD: Uh, uh. (Yes)
T: But not necessarily... 
SD: So when you say that something is true, what does that mean? [Pause]
T: It means that it does happen. It is real.
SD: Uh, uh. (Yes) It is real. So that, it means that's what really happens in the world?
T: Right.
SD: Okay, and you think that we can measure what really happens?
T: Uh, uh. (Yes) (C 84-85)

While she understood some aspects of science to be tentative, its basis is a static truth.

At the outset the study, Tyler understood there to be many conflicts between scientific knowledge and religious beliefs. She understood them both of them to represent ways to understand the world, and she was very aware of the conflict between evolutionary thought and many religious beliefs. This was a conflict that Tyler had encountered before the beginning of the study:
T: [Reading her pretest answer] What is your personal opinion of the theory of evolution? And I said, I believe in evolution to a certain extent. I also believe in creationism. I believe they came together, but I'm not sure of how. So the only reason that I believe in evolution some is because many of its points are proven facts.
SD: Okay. Like what points are proven facts?
T: Just, ah, about [pause] how animals have become more developed. . . I don't know. I don't know much about evolution.
SD: Okay.
T: But it's all confused with what I believe in the Bible.
SD: Can you talk a little bit about that confusion?
T: Yeah. Ah, ah I've heard some evolution theory that like animals, monkeys, and apes and stuff were put on the earth and that's how we've evolved. From them.
SD: Uh, uh. (Yes)
T: But then I've also believed that God put us on the earth as man.
SD: Uh, uh. (Yes)
T: So. But it seems like all these creation, evolution things have, they just seem so right. [Laughs] And so scientifically just right that
SD: Uh, uh. (Yes)
T: How can I believe that just man was put on the earth? I don't know. I believe that evolution did occur. But God had something to do with it. [Laughs] . . .
T: Yeah, I've always wondered about evolution.
SD: Uh, uh. (Yes) Like what have you wondered?
T: I've just wondered what's right. [Laughs] I mean I don't think I'll ever know what really, really happened when the earth was created. I don't know.
SD: Uh, uh. (Yes)
T: Just because there are so many questions to be answered. (C 26-27)

Tyler had achieved a partial resolution of her science/religious conflict by explaining that evolution occurred, but God had a hand in it. However, the passage above contains signs of her continued discomfort. At this point she used a theistic understanding of a process of gradual creation (Nelson, 1986), meaning that she understood evolution to occur but as a process controlled by God. However, she still remained unsure concerning human evolution. She explained that before this class she used to think all species except humans underwent evolution, and humans were placed on earth by God as an act of special creation. Her dissatisfaction with this explanation is seen in her question, "How can I believe that just man was put on the earth?" Early in the study, human evolution remained an important unresolved question for Tyler.
Aside from our discussions of evolution, Tyler seldom volunteered insight into her religious understandings. She attended church on a weekly basis, but because her parents were divorced, she attended a variety of denominations. She did not perceive her family to be particularly religious, instead she characterized them as very "moral." Tyler explained that she did not use a literal interpretation of the Bible because she did not accept the implications of a literal interpretation for the status of women and other minorities within society. While Tyler was not aware of her parents' views of evolution, it was clear that her mother had great reservations with this topic. In our interview, Tyler's mother voiced surprise when I described the scope of my study as she explained, "you don't want to hear what I think about evolution." (C 297)

Unlike Stephanie, Tyler was not explicit about the differences between her personal understandings and those of science, because she had less confidence in her scientific understandings and because she recognized scientific knowledge as a source of final authority. "The problem is I don't know anything about evolution." (C 48) In the description of her conceptual framework, I have attempted to separate Tyler's personal and scientific conceptions, but the differences were not as polarized as I had come to expect from Stephanie's interviews.

**Tyler's Conceptual Framework for Evolution**

**Initial framework**

**SD:** When I say something evolved, what does that mean in a science class?

**T:** It means that, I think it means that something was put on the earth real crude like, I don't know what the word it.

**SD:** Uh, uh. (Yes)

**T:** And that, through the years, and being in different settings and having to deal with different things in the environment, it became more advanced. (C 29)

Tyler's early explanation of evolution characterized many aspects of her conceptual framework for this topic. In keeping with her largely aesthetic view of nature, this explanation provided no explanation for a mechanism and instead emphasized the broad nature of evolutionary changes.
Nature of evolutionary changes.

As demonstrated by her comments above, Tyler understood evolution to include a slow process of change toward a "more advanced" organism. By more advanced, Tyler meant an evolutionary change makes the organism uniquely suited "according to their needs." (C 30) This conception of evolution describes production of many different organisms.

Tyler also understood evolutionary changes to be slowly and constantly occurring through "multiple acts." While Tyler could not fully explain what she meant by this phrase, she indicated that evolution occurred "several times" during the lineage of a group.

In the early interviews, it was difficult to persuade Tyler to express the conceptions she personally used to understand evolutionary changes. But during the third interview, she explained that the scientific explanation would account for the evolution of all organisms from some original biological progenitor. However, the conception she personally used was outlined in her concept map. She personally understood God to place the original "creatures" on the earth and change the organism through multiple acts of evolution, a process which eventually lead to the evolution of humans.

As implied in Tyler's description of evolution as an advancement, "change toward their needs," Tyler recognized much of evolutionary change to occur in response to the needs of an organism. The use of need was accompanied by a rejection of randomness or chance as a descriptor for evolutionary change.

T: [Discussing the evolution of webbed feet in ducks on the pretest] Well it just doesn't seem that webbed feet would just be a change mutation. I mean, that's kind of a big thing to have in an animal. You know what I'm saying?
SD: Big, yeah.
T: It's just, it's one of their major qualities, it just doesn't seem like it would be a chance that they got that. (C 18)
Finally, she had a vague conception of adaptation during the early interviews, explaining that "Adapt means to find things to do, so you can live better in that setting." She drew no distinction between genetic, behavioral, or proximal adaptations, but understood all of these to be forms of adaptations.

**Mechanism.**

As has been described, Tyler used only a very vague conception of the mechanism of evolutionary change in the early interviews. Explaining that, "I don't know how it happens," Tyler would describe the nature of the changes when asked about mechanisms. (C 26) However, when asked to "map specifically how you think it works," Tyler explained that:

- **T:** The creatures were put on the earth.
- **SD:** Uh, uh. (Yes)
- **T:** And the fittest creatures survived and advanced and the ones that were most fit in the environment kept surviving and the other ones pretty much died out and eventually ah, ah, more advanced creatures were developed. (C 72)

This answer demonstrates that Tyler used a conception of evolutionary change operating through the process of natural selection. But for Tyler, this was an implicit, tacit knowledge, and her conception of natural selection was the most important component of her understanding of the process of natural selection. This conception is different from the scientific conception of natural selection as operating on differential reproduction. Instead, Tyler understood natural selection to operate through the death of unfit individuals.

Tyler used a collage conception of fitness, like Brian, but she emphasized the age of the individual:

**Tyler:** [Explaining her pretest response to the most fit lion] I put that the fittest lion is Ben... Because first of all his size was just normal... He was just average and he had the most cubs, and he lived the longest. [Pause] And let’s see 14 of his children lived... Not 19 or 15, but its a good number I guess... And especially because he lived the longest. (C 2)
This collage conception of fitness changed in a later interview to one based on an organism's ability to survive. Any animal that could survive is fit, and the most "average" animal has the greatest potential to survive.

Congruent with her conception of natural selection as the major process of evolution, Tyler had an appreciation of the variation that must be present in an evolving populations. While her conception of a species was a group of animals that "share the same qualities" she understood this in a moderate fashion, "some of the same qualities." (C 90) She also had a conception of species as a variable phenomena, "There are a lot of different varieties in a species." (C 91) Despite her scientific populational understanding of a species, Tyler remained unsure of the taxonomic group in which evolution proceeds:

SD: What unit does evolution work on?
T: I would say not necessarily just individuals, but groups of things that are alike. (C 31)

Evidenced by her pretest responses, Tyler understood evolutionary changes to be essential to the improvement of the quality of a trait in a population. She explained that evolutionary changes appear as slow increases in an organism's "ability" to meet their "needs."

[Pretest answer to the evolution of webbed feet in ducks]
T: I think they probably got more and more webbing, just like they had to adapt. . . . So they had to get more and more webbing on their feet.
(C 18)

Despite the extent of Tyler's implicit knowledge of evolutionary process, she recognized there to be a large gap in her understanding. When discussing the evolution of webbed feet in ducks, Tyler murmured, "I don't know how they produce something in themselves." (C 20) But with additional questions, Tyler expressed some of her tentatively used conception for the origin of a trait:

T: [Reading her response to the evolution of speed in cheetahs] Okay, the earlier, slower cheetahs had to learn to run faster in order to survive. Those that couldn't change any, did not survive, but those that did became faster. Oh this is goofy! [Laughs] But those that became faster
mated with other healthy cheetahs and eventually through the mating cycles, cheetahs have become fast animals.

SD: So explain to me how it happens that cheetahs get so fast.
T: Because they had to learn to catch their prey.
SD: Uh, uh. (Yes)
T: And they, I guess they had to push themselves to go faster in order to get food. . . . But I don't know if mating with an animal that's also fast will make you have a fast animal. . . . I don't know if a cheetah that learned to run fast to catch its prey, I don't' know if it would have an offspring that was faster too.
SD: Uh, uh. (Yes)
T: I don't know if that's how evolution happens. You know? (C 23-24)

When pressed, Tyler used learning as a source of new variation in the population that produced the variation needed for natural selection. However, she was skeptical about the possibility of such variation becoming embedded in the genetic basis of the population.

When Tyler used learning as a process through which populations evolve, she was aware of all the connotations of that term:

T: [Reading her response to the pretest question about the evolution of immunity in mosquitoes] I put mosquitoes learned to adapt to their environment.
SD: Okay.
T: I guess it's like they learned that they had to adapt to DDT because in order to live. Then those that survive were, the fittest, the survival of the fittest.
SD: Okay, you picked the one that said they learned. What, what does that mean when you say that?
T: They, that they figured out what they had to do ah to live.
SD: I'm just trying to figure out what you mean by learned. You know, sometimes
T: They figured out what, what was going to kill them I guess. (C 19-20)

Halldén (1988) suggests that students use of learn is an artifact of communication. Tyler's comments do not suggest that she was framing a more complex conception with a familiar phrase. Instead, she understood that animals, both insects and mammals, can learn to change behaviors or physical reactions in order to survive. Learn was an accurate reflection of her understanding. However, while she offered this explanation, Tyler recognized the deficiencies of this explanation in terms of the genetic basis of evolution.
Another tentatively used conception for the origin of variation seen in Tyler's response was the use/disuse explanation.

T: [Reading her answer on the pretest concerning the evolution of blindness in cave salamanders] I said from living in caves, salamanders use very little of their sight. From not using their eyes they became nonfunctional and this trait was passed down to other generations. . . . I guess if you don't use something it does become dysfunctional.
SD: Uh, uh. (Yes) Where do you get that idea from?
T: Ah, from us! Just like if you don't use certain parts of you brain, you forget all about it. (C 25)

Tyler understood variation to occur because of the need for it, and this accounts for her rejection of the random aspect of evolution that is introduced through the use of mutation as the mechanism of variation:

T: [Reading a pretest answer] I put that they [webbed feet] appeared in ancestral ducks because they lived in the water and needed to swim. (C 17)
T: They [cheetahs] developed in their own ways, according to their needs. (C 30)

After Tyler discussed each of the possibilities for the origin of variation, she dismissed their use as a mechanism:

SD: So how did it [sight] go away [in the cave salamanders]? Do you have any idea?
T: No, not really. Just from not using it. I don't see, I don't understand the real science of how it goes away.
SD: Okay.
T: I don't know how to explain that. I just know from not using it. [Pause] The function went away and I guess when they had their offspring it just didn't work. See, I don't know! [Laughs] I don't know, I don't know how it happens! (C 25-26)

Tyler referred to "the real science" of the origin of a trait signifying that she recognized that her explanations were not scientifically valid. But at this point, she had no other viable conception, explaining "I really don't know what causes people or things to change." (C 31)

Before the fourth interview, Tyler was aware of the shortcomings of her knowledge. She realized that she could not scientifically explain the origin of variation in a population. But when Tyler was asked to complete the sorting task (ST, initial), she began to construct a scientific conception for this phenomenon. (These data are
reported in detail as this represents the initial construction of an important conception in evolutionary theory.)

SD: Okay, ah, and each one of these cards represents a different generation. Like this is one generation who would have offspring maybe and produce another generation. So each one of the cards represents a generation of rabbits.

T: What is that [pointing toward card of DNA model]?
SD: Ahm, this is ahm genetic material... and here's a piece breaking off it...

T: Is that a rabbit? [Pointing to a graphic with a rabbit in a hawk’s mouth]
SD: That's a rabbit, a dead rabbit.
T: Okay. [Laughs]...
SD: What’cha thinkin’?
T: I’m thinking, "I don’t know what to do."
SD: Okay. Now you don’t have to use all of them.
T: I don’t know where to put that in. [Pointing to the DNA card]
SD: Okay. Then we’ll just put this one to the side. And if you don’t want to use it, don’t use it. I just want you to explain how you understand it.
T: Okay. Well I guess you could put it in here [before the first brown rabbit card]. So.
SD: Would you put it in there?
T: Because something had to happen genetically for a brown rabbit to happen...
SD: Do you know a word for that?
T: Ahm, like a mutation?
SD: Yeah, that might explain it, yeah.
T: Uh, cross breeding? I don’t know. But a brown rabbit occurs. And here the hawk discovers the white rabbits. He likes to eat them more than the brown rabbits, well there’s just a couple of them now. Well let’s see. He’s eating more white rabbits. And the white rabbits are diminishing and the brown rabbits, there’s more of them.
SD: Uh, uh. (Yes)
T: ’Cause it’s easier for them to survive because there is more of their kind and less of the white rabbits.
SD: Uh, uh. (Yes)
T: And here’s he’s eaten all of the white ones but one.
SD: So if you could predict what would happen the next generation what do you think it would look like?
T: It’d be all brown.
SD: Yeah? Ah.
T: ’Cause obviously they can’t survive with the hawk around.
SD: Yeah. So would you call that evolution?
T: Uh, uh. (Yes)
SD: Uh, uh? (Yes) Here’s a question. You have something happening to make the first brown rabbit that’s here. Ahm, do you think this happening has anything to do with the hawk?
T: Ahm, (long pause), not really.
SD: Okay.
T: Well I guess yes. 'Cause somehow the genes were mixed up and more brown rabbits were produced
SD: Uh, uh. (Yes)
T: while the hawk was eating the white ones.
SD: Uh, uh. (Yes)
T: And then more brown rabbits became dominant. It's because the hawk ate the white rabbits that probably the brown rabbits started becoming dominant.
SD: Dominant, okay. When you use that word dominant, are you talking like ah you know you talk about genetics?
T: Genetics, yeah.
SD: Genetics, yeah? Okay. So something about the hawk being there makes that brown gene dominant?
T: Yeah. Right.
SD: Okay. Ahm, so what do you think about these guys, the two brown ones. Do you think that this has to keep happening over and over to get more brown ones? You know, like it happened.
T: It happened here, but then if these two ah
SD: She's pointing to the brown ones.
T: Yeah the two brown ones have offspring they're more likely to be brown.
SD: Uh, uh. (Yes)
T: So, do yeah, it does have to happen a few more times to the white ones. But once there are a few more brown ones
SD: Uh, uh. (Yes)
T: They'll produce offspring which will most likely be brown. And then they'll just naturally happen. (C 77-79)

This passage represents Tyler's first use of the concept of mutation in an explanation of evolutionary change. She also suggested crossbreeding, which she understood to be a type of hybridization, as a source of variation. Tyler used these possibilities, mutation and cross breeding, because they satisfied the genetic requirements she recognized as necessary to make her explanation plausible. This requirement was not met by any of her previously suggested mechanisms. Each of the two conceptions, mutation and crossbreeding, were then incorporated into Tyler's previously existing framework for evolutionary change.

Also of interest is Tyler's incorporation of this genetic change into her Mendelian understanding of inheritance of discrete traits. She understood changes to "become dominant" in a population and that dominance to be passed down to the next generation. Like Stephanie, Tyler has equated genetic dominance with ecological
dominance. This new conception was again incorporated in her pre-existing conceptual structure.

**Other biological knowledge.**

As demonstrated in the previous passage, Tyler had a firm understanding of the genetic basis of inherited traits, and she used a Mendelian conception of genetic inheritance. But like the students in the study by (Clough & Wood-Robinson, 1985a), Tyler's firm Mendelian conception wavered under certain conditions as shown in the prediction interview (PI-2, initial):

**SD:** [Two rats who have recently lost their tails meet and breed. What will their offspring look like?]
**T:** I think their offspring will have a long tail. I don't see how cutting off a tail has anything to do with the genes they had originally.

**SD:** If they were very young when this happened, like they were just born and something cut off their tails, would that change your answer?
**T:** Gosh, probably so. 'Cause they would have to grow up. [Pause] Ah it's kind of contradicting myself, but they would have to grow up without a tail. And it's just like they were born without a tail pretty much. . . . Gosh, but if it did come from the gene, then their offspring probably would have long tail. I don't know. (C 124-125)

Other conceptions Tyler used in understanding evolution were involved with her understanding of the origin of traits. She understood organisms to be capable of conscious decisions, not only in behavioral modifications (running faster) but also in physiological processes (immunity to DDT). In part, these naive conceptions may be attributed to Tyler's aesthetic view of nature. As mentioned previously, Tyler had never considered possible explanations for adaptations, so when pressed, she responded with simple, somewhat anthropomorphic responses.

**Human evolution.**

Tyler was most aware of the differences between the scientific conception and her personal understanding in the group of conceptions for human evolution. Tyler understood the scientific conception of evolution to explain that humans have evolved from "animals, monkeys, and apes and stuff." This view of evolution as directed toward human evolution was supported in Tyler's interview about instances (IAI-1,
initial). When shown a graphic with three species of bears, she discussed the specific characteristics of each of the bears. But when shown a graphic depicting a gorilla, a chimpanzee, and a human, she smiled and responded, "evolution." (C 93)

Tyler's understanding of the scientific conception of evolution differed from her personal explanation that humans were "just put on the earth" by God and all other species have evolved. (C 27) However, by the second interview, she began to question the validity of her personal understanding, "How can I believe that just man was put on the earth?" (C 27) This question remained unresolved through the initial interview period.

SD: What would you like to know if you could have any piece of knowledge that would help you understand evolution?
T: [Pause] I would like to know. [Pause] I would like to know how, I would like to know how humans were developed. I don't, I don't, I don't know. (C 28)

Related to this, Tyler was ambivalent about the relationship between humans, primates, and other animals.

T: I just don't, I don't consider myself related to an ape.
[Both laugh]
T: I don't know. 'Cause they just, they do seem kind of crude. And I don't know.
SD: So, ah, do you think we are related to anything?
T: I think we are related to them.
SD: You do? . . .
T: Oh, I think we are related to them. Yeah.
SD: Yeah?
T: I guess I shouldn't.
SD: Would you have said that before this year?
T: Ahm, not like four or five years ago, but in the last two or three years, yes.
SD: Okay. What do you think made that change?
T: Well just seeing, actually hearing a lot. . . And it seems like I went to ahm the Smithsonian in Washington.
SD: Uh, uh. (Yes)
T: And saw all that stuff about evolution. . . . And I don't know, just different things that I've seen. And just looking at the apes this year.
SD: Yeah?
T: Has made me think that they are more human like than I once thought. (C 97)

The issue of human relationships is one which depicts the process through which students make theoretical choices. Tyler's ambivalence is evident in this passage.
Personally she did not like the implications of a human/ape relationship, but factors continue to suggest that this is more plausible than she once thought. Notably, Tyler explained that this change began before this year and was catalyzed by a trip to a natural history museum and Ms. Hurston's unit on animal behavior. It is interesting to note that Tyler's hesitancy in accepting a human/ape relationship does not extend to a human/animal relationship:

**SD:** So do you have trouble classifying us as animals? What do you think about that statement?
**T:** No because I've always thought we're mammals.
**SD:** Uh, uh. (Yes)
**T:** And animals are mammals.
**SD:** Uh, uh. (Yes)
**T:** So that doesn't bother me.
**SD:** So we could be animals or we could be mammals. That's understood. But we've gone beyond primate? We're something else now?
**T:** Not totally.
**SD:** Oh, okay. Where do you, can you expand on the not totally?
**T:** Yeah because we still have a lot of the same characteristics.
**SD:** Uh, uh. (Yes)
**T:** That are the same but we are different obviously. (C 112)

**Evolutionary relationships.**

Tyler's species concept was not entirely typological or entirely a neo-Darwinian population conception. She recognizes a species as a group of organisms that shared "some qualities" and are "related to one another." (C 90-91) This is a recognition of a species in a typological manner, a common alternative conception. However, she also recognized the presents of considerable variation of characters within one species, a major feature of populational thinking and a feature of the Darwinian species concept. However, she made no mention of the ability to breed within a species and instead stressed a common core of characteristics as a sign of a species.

**Evidence for evolution.**

As an authority seeker, evidence supporting or refuting the theory of evolution was not a major feature of Tyler's conceptual framework. Tyler understood the "development" she perceived in natural organisms as a form of evidence for evolution.
But this was a vague conception, "I don't know, things have progressed, and they've just become more developed." (C 26) Related to this vague conception of development, Tyler explained that human anatomical similarities to other organisms is a persuasive form of evidence supporting evolution. Not surprisingly, Tyler understood the most important evidence refuting evolutionary theory as also focused on humans:

SD: How about some evidence that doesn't support [evolution], that refutes it? . . .
T: Goah! Ahm, we talk. And nothing else does. . . .
SD: So you think that, that kind of separates us from the other animals?
T: Right. Uh, uh. (Yes)
SD: And you think that biology needs to explain that somehow?
T: Uh, uh. (Yes) Yeah, because no other animal has a language like ours. (C 149)

Broad evolutionary theories.

As was reflected in her conceptions of human evolution, Tyler recognized the theory of evolution in terms of a theory of human evolution.

SD: Okay, so evolution produced man?
T: Right. That's what I've always thought what evolution meant. (C 50)

The theory of the creation of the earth never emerged as an important aspect of Tyler's understanding of evolution; instead she understood evolution's importance to be fundamentally concerned with the creation and changes within humans. She did not view the theory of evolution to be an integral part of biology.

Tyler's semester exam taken at the end of the initial interview period demonstrates that she had a conception of broad evolutionary theories such as the extinction of dinosaurs. In this exam she gave a thorough explanation of the major, competing extinction theories and identified the one she found to be the most reasonable explanation. However, unlike Stephanie and Brian, these broad evolutionary theories did not appear in Tyler's interviews. She did not use these theories in her everyday understanding of evolution. Because this evidence is found in an exam (Artifact-3), it is probable that Tyler acquired this knowledge shortly before
the exam, and so it did not play a major role in her conceptual framework for evolution.

**Natural history.**

Like Stephanie, Tyler demonstrated a very shallow knowledge of the natural history of historical or recent organisms. While Tyler was interested in nature, signified by her attitude in class when discussing organismal biology and her love of nature programs, she retained very little information regarding natural history. As has been discussed, she did not view organisms in mechanistic terms, and this view may have limited her construction of knowledge in this area. Coupled with the lack of natural history knowledge, Tyler demonstrated a sound understanding of taxonomy. While she was not familiar with many of the organisms discussed in the interviews about instances (IAI-1, initial), she could accurately categorize these animals and cite the reasons for this classification. She explained that she learned much of this material in her sixth grade biology class. Despite this taxonomic knowledge, Tyler had no conception of the evolutionary relationships of large taxa of organisms.

**History of evolutionary theory.**

Tyler made no mention of the history of evolutionary theory within the first segment of interviews. This does not indicate that she did not have these conceptions as part of her conceptual framework, but it does indicate that this was not a facet of her framework that she frequently used and applied. Tyler seemed to compartmentalize her knowledge. As shown in the previous passages related to Tyler’s belief in evolution, she did not synthesize different conceptions as she was asked to do. Based on this, it is plausible that Tyler’s conceptual framework contained historical conceptions, but, because the interviews did not overtly question this topic, she did not draw on this knowledge.
Belief system.

As has been outlined, Tyler's belief in evolutionary theory was undergoing a change in this initial period, a change that had begun some time before this class. Tyler understood the scientific explanation of evolution to describe the creation and changes of the human lineage. Her own initial beliefs described evolutionary changes for all other groups of organisms except humans, who were an isolated creation of God. But toward the end of the initial interviews, Tyler began to accept the scientific view of human relationships and their implication for human origins:

[Tyler looks over a graphic which shows a human boy, a gorilla, and a chimpanzee]
T: You have two monkeys and a little boy. [laughs]
SD: [Laughs] So what do you think about that? You're laughing.
T: I don't know... Ahm, it's kind of like he's [the boy] just another ape. [laughs]
SD: So what do you think about that? You're laughing as you say it.
T: Ahm, well, I guess they're all in the same big family.
SD: Uh, uh. [Yes] Do you think that really?
T: Yeah.
SD: You're frowning a little bit.
T: Well we've talked about that.
SD: Uh, uh. [Yes]
T: Yeah, I think they are. [Pause] Even though they don't look too much alike. [Small laugh]...
SD: So ahm, do you think humans can be classified the same way animals can be classified?...
T: Yeah.
SD: Okay, so we could be. So you don't have any problems calling us primates?...
T: Well I guess not, if I think about it that way. I mean I just like to call us humans, I wouldn't say.
SD: But can you say or are you comfortable saying that humans are primates? I sense some discomfort with that, like Yeeeeeah. Like maybe?
T: Yeah. Well what I think is maybe ahm, a long time ago we were more primates. [Small laugh]
SD: Okay, so really you, you would be more comfortable saying our ancestors were primates?
T: Right, it's like we've developed into something a little bit different than primates. (C 112)

The tenor of this exchange was slightly different than the meaning taken from a reading. While Tyler could recognize the plausibility of the scientific explanation, she was still very hesitant in accepting a human/ape relationship. This reluctance could be
based on the implications that such a relationship would have for her religious beliefs. In any case, the conceptual change for this issue remained a tentative one at the end of the initial interviews.

See Figure 16 for a summary of Tyler's initial conceptual framework.

<table>
<thead>
<tr>
<th>Human Evolution</th>
<th>Characteristics of Evolutionary Changes</th>
<th>Broad Evolutionary Theories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humans are animals</td>
<td>Evolution includes slow, constant changes</td>
<td>Evolution includes creation of first life and subsequent changes in humans and animals (R)</td>
</tr>
<tr>
<td>Humans are primates (R)</td>
<td>Evolution is a progression to more advanced organisms</td>
<td>Evolution includes only changes within taxa other than humans</td>
</tr>
<tr>
<td>Humans are a product of evolution (R)</td>
<td>Evolutionary changes are based on need</td>
<td></td>
</tr>
<tr>
<td>Humans are product of separate creation</td>
<td>Adaptations include all changes in response to environmental conditions</td>
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<table>
<thead>
<tr>
<th>Evidence for Evolution</th>
<th>Mechanism</th>
<th>Historical Aspects of Theory</th>
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<tr>
<td>Development of organisms</td>
<td>Variation caused by conscious decision, use/disuse and need</td>
<td></td>
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<tr>
<td>Similarities of humans to other organisms</td>
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</tr>
<tr>
<td>Development of human evolution</td>
<td>Evolving populations are variable</td>
<td></td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Related Biological Knowledge</th>
<th>Natural History</th>
<th>Evolutionary Relationships</th>
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<tr>
<td>Mendelian genetics</td>
<td>Knowledge of animal taxonomy</td>
<td>Species is a taxonomic group</td>
</tr>
<tr>
<td>Anthropomorphic approach to production of variation</td>
<td></td>
<td>Relation describes physical similarities</td>
</tr>
</tbody>
</table>

Note. Italics indicate instances of conceptual change. **Shaded block indicates conceptions based on belief.** Solid block indicates academic conception. (R) indicates rejection of conception.

Figure 16
Summary of Tyler's initial conceptual framework of evolution
Beliefs.

The most prominent changes which occurred in Tyler’s conceptual framework for evolution during the mid-year period may actually represent a change in her conceptual ecology. At the beginning of this mid-year interview period, Tyler demonstrated a construction of a science/religion dichotomy that was not previously present:

[A homework question]: Explain the difference in the types of answer you should expect when asking these two questions:
(a) How did Homo sapiens come to inhabit the Earth?
(b) Why did Homo sapiens come to inhabit the Earth?

[Tyler’s written response]
T: For question a, a scientific answer would be given, evolution explains how. But why is explained by something other than science—religion. God wanted us to be here on earth.

(Artifact 4)

This new conception was also reflected in her interviews:

T: I think science can prove that we have evolved.
SD: Uh, uh. (Yes) Would that mean anything to you? If we, if we did prove that we have evolved?
T: Yeah. (C 212)

T: Science just tells you how it works. It just explains how things are. But religion you believe in. I mean, you have to learn what religion is, but it's just belief 'cause there is nothing there, I mean you can't put your hand on something in religion like you can science. . . . I guess both of them could be right they just explain different things. (C 197)

T: So the answer to creationism is just faith.
SD: Uh, uh. (Yes)
T: I don't, there is never gonna' be any physical evidence to prove that one. (C 212)

Although Tyler had begun to establish a dichotomy between scientific and religious knowledge, she did recognize that there were points of overlap between the two ways of knowing. The use of this dichotomy allowed Tyler to be more explicit about the differences she perceived in her own, personal understandings of evolution and those of science. These differences will be discussed in the following sections.
Nature of evolutionary changes.

Tyler explained her personal understanding of evolutionary change to include small changes within a group. When shown three graphics depicting different phylogenetic trees, (a) evolution shown as a change of color within a group of butterflies, (b) evolution as a change leading to the creation of many vertebrate groups, and (c) evolution as a set of vertical changes within a group of armadillos, Tyler picked the vertical changes shown in (c) (IAI-2, midyear).

T: I would say this, the one with the armadillo.
SD: The one with the armadillo. Why?
T: Because they're basically alike....
T: I like this because it's a simpler change. That's just what I think is evolution.
SD: Okay, like a simple change?
T: Maybe it's not simple if you take it from the very beginning to the very end.... But all the stages in between are pretty simple. (C 167)

Her personal understanding of evolutionary change described limited changes:

T: I think they [organisms] do change inside a group a lot ....... but I don't think a whole new creature can come from one other thing. (C 177)

Tyler also became more explicit about her rejection of part of the scientific conceptions:

SD: How do you think the process of evolution works?...
T: Well, I still don't believe some of the things we learned about it [evolution].
SD: Okay, you don't?
T: No, not like the skipping. I don't remember the terms.
SD: Saltation?
T: Yeah.... Gradualism, that's what I guess.... I think that's believable. (C 205)

Tyler understood gradual evolutionary changes as a process that increased the complexity of organisms, as shown in her concept map constructed mid-year (CM-2, mid-year). She did not understand complexity to be equivalent with perfection. Instead she understood complexity as a closer "fit" of an organism to its environment (C 210), as in "An amoeba might be perfect in his little world." (C 164) But Tyler continued to view the most complex organisms to be humans.
Tyler also understood evolutionary changes to be ordered, but without a direct design. Instead, she understood the order as a pathway toward "development" of complexity. (C 224) Related to this understanding of order, Tyler rejected randomness in her personal conception of evolutionary change.

\[\text{T: Chance. I don't know. 'Cause I don't under. I don't know. Yeah, chance because things are made by chance. . . . In evolution.} \]
\[\text{SD: Okay.} \]
\[\text{T: But I don't believe all this skipping. You know what I'm talking about?} \]
\[\text{SD: The saltation stuff?} \]
\[\text{T: Yeah. [C 221]} \]

Tyler understood random and chance to causing large, drastic changes. While she understood this to be an aspect of the scientific conception of evolutionary change, she could not reconcile these characteristics to her personal conceptions.

During the mid-year, Tyler began to understand all evolutionary changes as a form of adaptation:

\[\text{T: Evolution is a change in the population.} \]
\[\text{SD: Ah, and where does the change come from?} \]
\[\text{T: [Pause] Changes come from, comes from, come from living in the environment. It comes from} \]
\[\text{SD: Okay.} \]
\[\text{T: Adapting. (C 214)} \]

This conception of evolution is congruent with Tyler's rejection of the random aspect of evolutionary changes. Instead, Tyler understood evolutionary changes as largely determined by the organism's environment.

Despite her conceptions of evolution as being slow, subtle, and ordered, Tyler explained that evolutionary changes could never be predicted. But Tyler understood the unpredictability to be caused by an ever changing earth and not through the inclusion of mutations.

\[\text{T: The world just don't stay in one state. It's never gonna' be the same. (C 161)} \]
\[\text{T: [Evolutionary changes] will never be the same because the earth is not gonna' be all the same. . . . I don't know, funky things happen. (C 162)} \]
Mechanism.

As suggested by her understanding of evolutionary changes as adaptations, Tyler's conception of the mechanism of evolutionary change revolved around need.

SD: So what causes mutations? Do you know?
T: When something changes outside . . . that effects them . . . and they have to change to adapt to that.
SD: Okay, ahm, so if an organism has like a need to adapt to the environment, . . . , a mutation will happen?
T: Yeah. (C 226)

Tyler retained the use of need in her conception, but the conception of mutation as a source of variation was introduced into her pre-existing explanation for the mechanism of evolutionary change.

Tyler's understanding of need as an integral conception in an explanation of mechanism was also signified by her response to the interview about instances which tested her understanding of harmful and beneficial mutations (PI-1, mid-year). Tyler recognized only beneficial mutations as possibilities for mutation. This choice is congruent with her need-based conception of the process of evolutionary changes along with her rejection of randomness and chance as characteristics of evolutionary change. As is suggested by this conceptual framework, during the mid-year period, Tyler had no conception of genetic drift as a mechanism of evolutionary change.

Shown in her concept map constructed in response to the request, "map your understanding of the process of evolution," Tyler's understanding of mechanism became much more complex and differentiated during the mid-year period (CM-2, mid-year). (See Appendix G for this concept map.) She used eight concepts for this map which described the process as a result of natural selection operating in a population. While the basis of this conception was not a great deal different from her initial framework, she was capable of using conceptions of natural selection in a much more direct and explicit manner.

Although Tyler understood natural selection to be the most important aspect of the mechanism of evolution, she did understand mutations to be a component of the
overall process. But she did not view them as an essential aspect. Her concept map of process did not include mutation as a conception. When asked to construct a map of her understanding of the process using seed concepts (CM-3, mid-year), Tyler included mutation only at the bottom of the map. Tyler incorporated mutation in a superficial manner by placing it within the confines of a pre-existing conceptual framework of operation of natural selection. This was also demonstrated in Tyler's response to the DNA card on the sorting task (ST, mid-year):

T: The mutation [that produced the brown trait] may have happened more so because of the hawk. The rabbits needed to change. (C 217)

Using natural selection, Tyler maintained her conception of the importance of variation in a population, but she remained unable to account for the original production of that variation.

**Human evolution.**

While Tyler resolved much of the conflict which had existed between science and religion, she continued to be perplexed by the question of human evolution during the mid-year period. Personally, she believed that humans were created by God. However, she understood the scientific conception to include the evolution of humans from an ancestral species. While it appeared that Tyler had established a strict dichotomy to allow her use of both of these conceptions, there were signs that the conflict remained, explaining "It seems like there should be an answer for both." (C 211)

**Natural history.**

SD: How old do you think the earth is? . . .
T: Billions of years.
SD: Billions? Why do you say that?
T: Well, we've been on it for tons of years. But then all the dinosaurs. I mean I don't know if they were millions or billions but.
SD: Can you differentiate between those two?
T: No.
SD: No?
T: Because something could have happened before dinosaurs, I don't know. . . .
SD: So now you're thinking that dinosaurs were the first things to live?
T: Uh, uh. (Yes) but the earth could have existed a long time before that. (C 157-158)

This passage demonstrates Tyler's conceptions of:

(a) the extreme age of the earth as well as her inability to distinguish between large magnitudes,

(b) dinosaurs and humans being the only notable life forms,

(c) dinosaurs as the initial life forms.

The inability to distinguish large amounts of time was also documented in Stephanie case study as well as in a study by Renner et al. (1981). Despite her recognition of a changing earth, the other aspects of this portion of her conceptual framework suggest a naïveté about the historical record of organisms. Her recognition of humans and dinosaurs as the only major groups of organisms suggests that Tyler was not interested in this aspect of natural history.

**Evolutionary relationships.**

Tyler's conceptions of evolutionary relationships remained largely unchanged in this mid-year period. However, her species concept did undergo a subtle alteration. While she continued to use a largely typological species concept, she introduced the ability to successfully reproduce as another characteristic of a species. This is not yet a scientific species concept, but it does represent a change toward the construction of a scientific conception.

**Other biological knowledge.**

While Tyler's conceptual framework for the other aspects of related biological knowledge remained largely unchanged, one aspect was highlighted during the mid-year period. During the initial interviews, Tyler referred to the ability of organisms to learn behaviors. During the mid-year period, this conception was further displayed when Tyler discussed the ability of plants to bend toward a light source:

**SD:** Okay, ah, think about a plant. You know they move to the light? After a couple of days their stems will turn around and orient toward the light.
T: Uh, uh. (Yes)
SD: Do you think that is a learned thing or an automatic sort of thing?
T: I would say it's learned.
SD: Learned?
T: Yeah.
SD: How does a plant learn to do something?
T: Well it wouldn't ah, it just knows what it has to do to survive.
SD: Okay.
T: It wouldn't be there . . . if it didn't learn to do those things. I don't think a plant is made. Well I guess they are. But I don't think a plant is made to automatically turning toward the sun. (C 191)

Once again Tyler's understanding of learning provides evidence that students can be very anthropomorphic in their understanding of biological organisms. While this passage reflects Tyler's anthropomorphic conceptions of biological processes, it remains to be determined if the mode of communication simply reflects this conception or if it actually creates or changes a conception.

The other groups of conceptions, including the historical aspect of the theory, the use of broad evolutionary theories, and Tyler's choice of evolutionary evidence, were retained unchanged during the mid-year period.

See Figure 17 for a summary of Tyler's mid-year conceptual framework for evolution.

Year-end framework

Belief system.

By the end of the school year, Tyler had resolved the conflict between her personal beliefs and what she understood as the scientific conception of evolution. When shown the graphic depicting the gorilla, the chimpanzee, and the human child, Tyler commented:

T: They're all related.
SD: Are they, really? You know you can talk to me.
T: I know.
[Both laugh]
T: Yeah, somehow they are. Well obviously these two are. [She points the picture of the chimpanzee and gorilla]
SD: Why obviously those two? Because they look kind of different?

T: Cause ahm, they're the same animal. They, they're just the same, the same, basically the same.
### Evidence for Evolution

- Development of organisms*
- Similarities of humans to other organisms*

### Related Biological Knowledge

- Mendelian genetics*
- Anthropomorphic approach to production of variation*

### Characteristics of Evolutionary Changes

- Evolution includes slow, constant changes within a group
- Evolution includes drastic changes between groups (R)
- Evolution is a progression to more advanced (complex) organisms*
- Evolutionary changes are ordered but not predictable*
- Evolutionary changes are based on need*
- Adaptations include all changes in response to environmental conditions*

### Mechanism

- Variation caused by conscious
- Variation caused by mutation
- All mutations are beneficial
- Most important component of process is natural selection
- Evolving populations are variable*
- Natural selection works through death of unfit individuals*
- Collage conception of fitness*
- Evolution includes an increase in the quality of a trait*

### Broad Evolutionary Theories

- Evolution includes creation of first life and subsequent changes in humans and animals (R)*
- Evolution includes only changes within taxa other than humans*

### Historical Aspects of Theory

### Natural History

- Earth is continually changing
- Dinosaurs were initial life form
- Scientific conception of taxonomy*

### Evolutionary Relationships

- Species concept based on characters and ability to breed

---

**Note.** Italics indicate instances of conceptual change.  
* indicates retention of conception from previous description.  
Shaded block indicates conceptions based on belief.  
Solid block indicates academic conception.  
(R) indicates rejection of conception.

---

**Figure 17**  
Summary of Tyler's mid-year conceptual framework for evolution

**SD:** Uh, uh. (Yes)  
**T:** They're both sitting on their behinds with their long arms. All brown and hair all over them. And he's not the same animal. [Pointing to the human boy] . . . But  
**SD:** But what?  
**T:** But somehow he traces back to these. . . . I think it could be explained scientifically somehow.
SD: Uh, uh. (Yes) So are you still uncomfortable with it?
T: [Pause] No. (C 239)

This resolution resulted in Tyler's use of a gradual creationist conception of human and biological diversity, a conception which explains that God put the original "creatures" on the earth, and evolution occurred within those creatures (Nelson, 1986).

**Nature of evolutionary changes.**

During the mid-year period, Tyler rejected the possibility of large scale evolutionary changes, but the concept map drawn at the end of the study indicates that this conception had changed by the year-end. At this point, she understood evolutionary changes as being both "radical and minor." (See Appendix G for CM-2, year-end.)

Tyler also expanded her conception of evolution to include changes in both humans and other organisms. This conception is demonstrated in her answers to the posttest question "What is your personal opinion of the theory of evolution?":

T: [Written answer] Evolution is a change in a species over a long period of time. Evolution began when the earth was created, but it still is happening today. Not only did evolution occur in humans, but it can occur in any species alive. (Posttest #9)

Despite these expanded conceptions, Tyler continued to view evolutionary changes as leading toward "complexity" which she understood as greater "detail" and "advancement." (C 287) While Tyler continued to understand humans as the most complex of all biological organisms, by year-end, she understood evolution to described the change of all organisms.

The final area of change within Tyler's conceptual framework for the nature of evolutionary changes was in her conception of adaptations. In the mid-year period, Tyler understood adaptations as including any changes in an organism in response to their environment. By the year-end period, Tyler had streamlined this broad conception:

SD: You used the word adaptation, like they adapt to their environment. What does that mean?
T: Learn to survive in it. Ah.
SD: Uh, uh. (Yes)
T: It's like getting used to... something.
SD: Uh, uh. (Yes)
T: It's not like; no. It's not like you can teach it to a... It's just from being there you learn what things are like.
SD: Uh, uh. (Yes) So it's kind of a thing you gain from experience?
T: Yeah.
SD: Okay, so what causes adaptation?
T: When something changes. When the environment changes... .
SD: Okay. Do you know if adaptations are linked at all to mutation?
T: Ah, I don't know. (C 242-243)

As demonstrated here, Tyler used adaptations in their proximal sense of a rapid change in an individual in response to a change in the environment. Unlike Brian and Stephanie, Tyler failed to recognize the multiple meanings of biological adaptation (Lucas, 1971). This narrow conception of adaptation is interesting when it is considered that Tyler understood all evolutionary changes to occur through adaptations. As has described by Cummins and Remsen (1992), Tyler demonstrated a difficulty in distinguishing proximate and ultimate changes. This difficulty is particularly prominent in Tyler's inability to recognize the linkage of mutations and adaptations.

**Mechanism.**

Tyler demonstrated use of a more integrated conception of the role of mutations in the mechanism of evolution by year-end. As reflected in her concept map (CM-2, year-end), Tyler understood the role of mutation as being essential to the actions of natural selection. This conception was also seen in her response to the sorting task (ST, year-end) in which she explained that both mutations and natural selection must occur in order for an evolutionary change to come about.

While Tyler began to understand mutation as being a necessity in the process of evolution, her conceptions of mutations continued to be very different from the scientific conception. As demonstrated in her response to the bear mutation graphic (PI-1, year-end), Tyler understood mutations as occurring largely because they are beneficial to a population:
SD: So you don't think a mutation to [lose all body hair] would happen?
T: I mean, well it doesn't seem logical to me.
SD: It doesn't seem logical. Do you think it would, it could happen?
T: I'm sure it could, it seems like anything could happen now. [Small laugh] . . . I'm sure it could but I don't think it would. (C 269)

But the conception Tyler applied differed from her more formally expressed conception of mutations:

SD: Do you think that the majority of mutations that happen in a group are beneficial?
T: Ah, the majority yes, all no. (C 269)

In the same interview session in which Tyler defined mutations as random events, she also explained that only beneficial mutations were probable. When the logical inconsistency of these two explanations was brought to Tyler's attention, she recognized no need to change her answers saying "I have no problem with that." (C 229) As mentioned in the descriptive section, Tyler often compartmentalized her knowledge and, unlike Stephanie or Brian, she was not typically driven to reconcile conflicting knowledge claims. Tyler was capable of providing a rote description of mutation, but the conception she used and applied was very different. Using the definition of meaningful learning provided by Smith et al. (1993), Tyler did not understand the conception of mutation in a meaningful manner.

Not surprisingly, Tyler did not often apply any conception of mutation, scientific or alternative, toward understanding an evolutionary event. In the posttest, Tyler did not use mutation in her explanation of the evolution of speed in cheetahs and she used it in a very tentative answer in the question referring to the evolution of blindness in cave salamanders:

T: [Written answer] Either a mutation could have happened that caused their blindness or since they have no use for their eyes, their vision could have gotten worse and worse. Eventually they lost all sight. (Posttest #8)
This answer indicates that while Tyler recognized the applicability of the conception of mutation, she continued to judge it to be a less plausible response than the use/disuse explanation for the origin of a trait.

Tyler's posttest responses taken with her response to the class final exam provide some insight into her alternative conception of mutation. When asked to the comment on the evolutionary implications of a cartoon depicting the morphological change in a stick figure, Tyler responded:

T: A mutation definitely occurred in the beginning of the evolutionary process. This creature went from having no limbs to having four limbs in one step. . . . (Artifact 7, #4)

Tyler's conception of mutation was as a source of drastic change, such as a sudden occurrence of "having four limbs." In other instances, such as what she perceived as the gradual evolution of speed in cheetahs or blindness in salamanders or immunity in mosquitoes, she understood her pre-existing, alternative conceptions to be more applicable. While she constructed a conception for mutation, this conception was one of such severe change that she found few instances where it could be successfully applied.

Tyler used a conception of evolutionary events as gradual changes or drastic changes:

T: Evolution is a change through natural selection and mutation over time in a species.  
SD: Uh, uh. (Yes)  
T: Ahm, [pause], species, they can it's like they can totally change or they can change to fit their environment. . . .  
SD: You put down here that change can be radical or it can be minor.  
T: Yeah. (C 286)

This acceptance of radical change was a recent phenomena, as described in the preceding section, and obviously was one which Tyler had yet to become comfortable. While she recognized that sudden changes could occur through mutations, she did not recognize this type of evolution as being very common. Instead, Tyler understood most evolutionary changes to occur through the gradual change in the quality of a trait.
which was quietly magnified in each generation, "It just seemed like that when [a species is evolving] that each generation would get a little bit more [of a trait]." (C 289)

**Human evolution.**

As was discussed in the section on beliefs, by the end of the school year, Tyler had begun to understand humans to be the result of evolution from an ancestral primate.

T: [Written answer] Studying evolution this year has really made me reconsider what I have always believed about our origin. Actually, the knowledge confused me a lot because I was torn between what to believe. I was always set on creationism because I have never known anything else. But after learning much about evolution this year I realize the facts and discoveries made cannot be disputed. Evolution occurred and is still occurring today. I can answer many questions that would have not been answered other wise. The knowledge I gained in our anthropology unit has further supported my belief in evolution. The idea that we descended from gorillas is fascinating and quite important. And studying the skulls of the first creatures found million of years ago through the skulls of today, it is obvious to me that we do stem from one common origin. . . . (Artifact 7, # 1)

The latter portions of this passage indicate that Tyler used the alternative conception that humans stemmed from a currently existing species of primates ("we descended from gorillas"). Despite its obvious logical limitations, she continued to accept the plausibility of this conception. Her acceptance was due more to what she perceived as the theory's scientific authority than to its logical coherence.

**Natural history.**

Most aspects of Tyler's conceptual framework for natural history were retained at year-end. However, these interviews demonstrated that Tyler had begun to apply her knowledge of evolution to understand variation within organisms. Looking at a graphic of three species of bears, she commented:

T: They're very different [because] they live in different places.
SD: Yeah?
T: And they had to [pause] adapt to those places you know, and that changes them I'm sure. (C 238)
While this passage demonstrates that Tyler was capable of a more mechanistic approach to understanding nature, she continued to use a largely aesthetic view of the natural world:

**SD:** Do you see [nature] as competitive?
**T:** Competitive? It's never been a word I've thought of.
**SD:** No? Okay.
**T:** No.
**SD:** So how would you characterize it?
**T:** Nature? I just think of nature as being just wonderful.
**SD:** Uh, uh. (Yes)
**T:** Just so peaceful. (C 266)

**Broad evolutionary theories.**

Although most aspects of Tyler's conceptual framework for broad evolutionary theories were retained, subtle differences were seen. One difference was in her perception of the scope of the evolutionary theory.

**T:** I used to think of evolution as just when we came to be. . . . I think it is now the change in a species. . . . And I think it's going on all the time.
**SD:** Okay, so it [evolution] would include both the creation of life and
**T:** Change now. (C 267)

Even though she recognized the production of life as an aspect of evolutionary theory, Tyler never discussed the strength or weaknesses of the scientific explanation of this event. Judging from her comments, Tyler understood the most important question in the theory of evolution to be "Are humans related to primates?" The question of the original creation of life was less influential.

In the final exam Tyler wrote:

**T:** The most important theory we have learned about this year is the theory of evolution. This explains our origin and why we are what we are today. . . . (Artifact 7, #1)

Once again, while it can be argued that a student's response to an exam may reflect only her/his scientific conceptions, it is important to recognize that Tyler's scientific conceptual framework for biology placed so much emphasis on evolutionary theory.
The other groups of conceptions, the historical aspect of evolutionary theory, her choice of evolutionary evidence, and her related biological knowledge were retained unchanged at year-end.

See Figure 18 for a summary of Tyler's year-end conceptual framework for evolution.

Summary of year long conceptual change

Tyler's case study provides valuable insight into the influences of a learner's conceptual ecology when it is compared with Stephanie's. Like Stephanie, Tyler could be considered to be a gradual creationist. But, unlike Stephanie, Tyler displayed extreme personal discomfort when discussing topics in which scientific knowledge and religious belief differed. Tyler understood the most important issue of this conflict to be the question of human speciation. Because Tyler approached biology as an authority seeker, she often attempted to resolve scientific and religious conflict through eliciting outside advice. Tyler, as the authority seeker, achieved a resolution of her perceived conflict. This resolution took the form of Tyler's acceptance of her conception of human speciation and a personal rejection of the special creation of humans. Accompanying this shift in Tyler's conceptual ecology, she also experienced conceptual change toward the scientific explanations of evolutionary change. The most important of these changes was her construction of the random aspects of evolution as introduced through mutation and a simultaneous rejection of need as the driving mechanism for evolutionary change. Despite these changes, at the end of the school year, Tyler was still involved in the process of learning evolution. She continued to apply her previous existing conceptions of evolutionary change in addition to her newly constructed conceptions.

While Tyler's conceptions for the process of evolutionary change underwent substantial change, it could be argued that these changes were based on an uninformed acceptance of a partial scientific framework. Uninformed is used here because
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<td>Evolution includes large scale and subtle changes</td>
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<tr>
<td>Humans are primates*</td>
<td>Evolution is a progression to more advanced (complex) organisms*</td>
<td>Evolution includes only changes within taxa other than humans*</td>
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<td>Humans are a product of evolution*</td>
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**Note.** Italics indicate instances of conceptual change.
* indicates retention of conception from previous description.
Shaded block indicates conceptions based on belief.
Solid block indicates academic conception.

**Figure 18**

Summary of Tyler's year-end conceptual framework for evolution

important aspects of a fundamental understanding of evolutionary change were not present in Tyler's conceptual framework. She had no conception of the competitive aspects of natural systems. Likewise, she had an alternative view of the process of speciation, as was demonstrated in her explanation of human speciation.
Despite these missing components, Tyler was becoming more mechanistic in her approach to biological problems. Her aesthetic orientation was undergoing a shift toward a more scientific one.

Meredith: Biologist as Pragmatist

Meredith was selected for participation in the interview process for a variety of reasons: (a) she used several alternative conceptions of evolutionary theory as demonstrated in her answers to the Bishop and Anderson (1985) exam, (b) she considered herself to be religious, but she had constructed a science/religion dichotomy before the outset of the course, and (c) she was not overly interested in biology. These characteristics made Meredith distinctly different from each of the other three students, and it was judged that her participation would contribute toward an understanding of the process of conceptual change.

Meredith was a senior girl who sat toward the front of Hurston's Biology II class. Like Tyler, Meredith seldom offered an answer in the whole class discussions unless she was directly called upon by the teacher. Also like Tyler, once the large group fractured into the typical small, working groups, Meredith was very vocal and she often asked questions of her co-workers and the teacher. I had a comfortable relationship with Meredith from the outset, and in laboratory situations she would often ask for my guidance so I worked with her small group frequently. Because of our close classroom relationship, the interviews with Meredith were very congenial. But unlike Tyler, Meredith's answers were direct and succinct; she followed very few tangents in conversation. While Meredith always appeared to be engaged in our talks, she seldom mused over her answers; once given, Meredith would not alter her answers or refer back to earlier questions during an interview.

I understood Meredith to approach to biology in a very pragmatic fashion, as shown in the following passage:
M: And, ahm, what I'm talking about creationism is that Genesis in the Bible is just saying ahm why, why everything was created and not how. And, I think a lot of people don't realize that that's what it's saying. . .
SD: Have you always thought this or is this something you've worked out for yourself later on?
M: Ahm, no, I mean, what, what do you mean?
SD: You know, that, that the thing that Genesis is the why and the science is the how? Is that
M: Oh. . . . Yeah, that, ah, that's something I, I've not thought all my life. I mean,
SD: Uh hum.
M: Once I started reading the Bible more, that's what I realized.
SD: Uh hum. So that's something that you've
M: I've never read
SD: worked out for yourself?
M: Yeah, I never really thought much about it before.
SD: Uh uh. (Yes)
M: I used to not. I very rarely think about it [laughter] to tell you the truth. (A 29)

Unlike Brian and Stephanie, Meredith did not commonly attempt to relate one theory to another. Instead, she understood a topic only in its application to her schoolwork.

While Meredith worked hard in the biology class, she wasn't interested in biology as much as she was interested in doing well in school:

SD: Ahm do you think biology is real useful to you out of the classroom? What you learn in biology, do you use it more than just in school? . . .
M: No, I mean, not too much. . . . It's not something that I use everyday. . . . I've never really been benefited by it other than tests and things like that. But, ahm, I mean it's just, you need to know that kind of thing just to
SD: Uh, uh. (Yes)
M: to be educated. (A 150-151)

Perhaps the pragmatism that characterized Meredith's approach to biology was forced on her by her demands of school. Talks with Meredith were constantly peppered with comments of exams, assignments, and grades. Both Meredith and her parents explained that her time away from school was spent completing homework assignments and college applications. Because of this, she watched little television and enjoyed no leisure reading. "I only have time to read what's required." [S #7]

However, she made time for the track team and in past years had played basketball. While Meredith worked diligently on her school work, this seemed to take a form of
socialization for her. She was a member of a small group of senior girls who completed assignments together after school hours.

During classroom observations, I repeatedly observed Meredith consulting her oversized calendar which contained all her school assignments. Despite her diligence, Meredith was often forced to finish assignments during her classes. She was struggling to achieve the grades necessary for a college scholarship, and because of this struggle the quality of both her personal and intellectual life was sacrificed. While Meredith did not reflect on her biological knowledge, she participated in little reflection on any academic topic.

Meredith's father explained, "I don't know that she has a great academic interest in anything." (A 330) Despite her concentration, no single subject captured her attention. Her favorite subjects were mathematics and English, because both of these "came easy" for her. (A 48) However, during the year of the study Meredith particularly enjoyed her World History class because of the teacher's intriguing lectures.

At the outset of the study, Meredith had planned to become a medical doctor. During two previous summers she volunteered in hospitals and found that she enjoyed working in health care. Meredith enrolled in the Biology II course because she knew that she would need many science courses in college in order to pursue her career. But during the course of the study, Meredith decided to study nursing. She explained she made this change because nursing requires a short time of preparation, and the schools are not extremely competitive. This career choice was also selected because of the many scholarships available to nursing students. She understood that nursing would allow her to work in health-care in the role of a caretaker. Keeping in mind later family plans, Meredith understood the lower salary of nursing to be outweighed by the life-style benefits of this career.
Meredith's Conceptual Ecology

The most striking aspect of Meredith's conceptual ecology was found in the intersection of her scientific epistemology and religious orientation. While both science and religion were very meaningful to her, she understood them to be completely separate in their goals and methods:

M: [Science] allows us to see how thing are working. How the world around us is you know
SD: Uh, uh. (Yes)
M: Operating and all those thing. It doesn't necessarily tell us why.
SD: What does? . . .
M: Religion, it's more the, the why's.
SD: Do you see science and religion has having some amount of overlap? Or, do you see them as completely separate? In your mind.
M: Ahm, well, I think that they're separate in that ahm one of 'em you know is explaining how things are happening and the other one is telling why. But, ahm, there's overlap in that these are dealing sometimes with the, dealing with the same thing. . . .
SD: So how do you separate the two? . . .
M: Well, ahm, the way well religion is you know a faith that you have.
SD: Uh, uh. (Yes)
M: And ah, you can say, you know, the the earth was created through faith, but not ahm. The way I separate it, I think, is that in science I have you know facts just to base evolution on.
SD: Uh, uh. (Yes)
M: And all that kind of thing you know. [Science] is more hard facts. But religion is more, it's more of a belief through faith.
SD: Uh, uh. (Yes) And faith being? How would you describe what faith is?
M: Ahm it's hard to explain. But it's a belief that you have not it's not, it can't necessarily always ahm be based on tangible thing. . . .

SD: So you think things are
M: Yeah, I think they are pretty separate. (A 203-205)

Before the study began, Meredith applied this dichotomy to the area of evolution and resolved any of the conflicts that might have occurred:

M: [Reading her answer to the pretest questions regarding her opinion of the theory of evolution.] I do believe that animals had evolved from their forefathers while I believe in creationism also. I feel we have a lot of proof for evolution that I think comes into play. What, what I wasn't really clear with my answer here.
SD: Okay.
M: Ah, I mean, evolution is, I mean, I definitely believe in evolution. And I think we just have too much evidence for someone not to believe it.
SD: Uh, uh. (Yes)
M: What I'm talking about creationism is that Genesis in the Bible is just saying ahm why, why everything was created and not how. Evolution is how everything was created. (A 27-28)

From the outset of the course, Meredith used a theistic understanding of evolution in which evolution is understood as the mechanism through which a creator operates (Nelson, 1986). Meredith accepted evolution as a valid biological process producing a firm historical record, and she understood that the study of this process and its record as being a scientific endeavor. However, the existence of God was not something Meredith recognized as requiring tangible support, because she understood religious and scientific knowledge as being distinctly separate.

Meredith described herself as a religious person; she and her family regularly attended a Presbyterian church in the city. While it was evident in our conversations that Meredith did ponder religious matters, religion did not appear to be a focal point of Meredith's energies. Recently her church related activities had been drastically curtailed by her school responsibilities. She explained, "I just don't have time for that anymore." (A 142) Congruent with her understanding of the limits of religious belief, Meredith used a metaphysical or religious world view only in regard to human activities. While she understood human life to have a fundamental meaning and plan, this understanding did not extend toward the natural world.

Although Meredith did not have a strong religious orientation, neither she did have a strong scientific orientation. Meredith enrolled in this science class because she felt she learned very little biology in her previous biology class, and she realized that this discipline was needed in college. Her father explained that Meredith was "not so much interested science as she is interested in nursing." (A 330) For Meredith, science was a means to an end. She enjoyed Ms. Hurston's class, but this was not her favorite class or favorite subject. As was discussed in her description, Meredith did not feel biology was a subject that she applied in her life, instead it was a subject to master in order to "be educated." (A 151)
While Meredith did not have a strong scientific orientation, she was typically very rational in her consideration of natural topics. Like Brian, Stephanie, and Tyler, Meredith was not interested in pseudoscientific topics. She dismissed these topics as "National Inquirer sorts of things." (A 52) When she considered the natural world, she used a naturalistic world view, understanding natural phenomena in terms of cause and effects and looking for the mechanisms behind occurrences (Coben, 1993).

Meredith used a realist epistemology of scientific knowledge, but she understood scientific knowledge to have a tentative, contextual nature.

M: Aspects of science can change.
SD: Uh, uh. (Yes)
M: Like ahm you know, like through more ahm study and experimentation, maybe new things will be ah found and discovered . . .
SD: Uh, uh. (Yes)
M: that would change what was once believed. And I mean, that's how it could change. (A 79)

While Meredith was a realist, she was not a naive realist.

Meredith also had a scientific conception of the relative importance of facts, hypotheses, and theories in science.

M: [An] hypothesis would be what you ah expect to happen. You really haven't ahm you know, you've done some research and everything, but you kinda' think this is what's gonna' happen.
SD: Uh, uh. (Yes)
M: I think a theory more comes out of ahm, testing your hypothesis.
SD: Okay, so how about the difference between a scientific theory and scientific facts?
M: Ahm I'd say that . . . theory, you know, it can be changed through more study and everything. But, facts, I mean, they're not gonna' change. It's either it's true or it's not true.
SD: So which one, you know, which one do you think has more weight in science? Has more importance?
M: Ahm, well, probably ahm like I would say maybe the theory because ahm, no you can't, if all you have was [sic] facts, there wouldn't be anything to work with. (A 78)

While her parents described Meredith as a student who was not very interested in biology, it became evident during our discussions that Meredith had a knowledge of biology that was gained from outside the classroom. When discussing the organisms in the interviews about instances, Meredith would augment her explanations with
examples taken from local natural flora and fauna. For instance, she knew that the
local oak trees included several different species, and she could recite many of their
common names. When questioned about this knowledge, she explained that her father
is a "nature nut." Because of this, family vacations centered around hiking in state
parks and trips to natural history museums. While Meredith seemed mildly interested
in this sort of knowledge, nature did not hold the attraction for her as it did her father.

M's father: She's receptive to that sort of thing, but she won't initiate it,
and she probably won't pursue it. . . . She's not one to go wandering
outside, looking at things. (A 333)

Although Meredith was not keenly interested in nature, the influence of
families activities was reflected in her scope of knowledge. Toward the end of the
semester, we discussed her views on human population. She felt that humans should
be limited to two children per couple because of the stress overpopulation places on
natural systems. This view was one she shared with her parents, and this topic was
often discussed at her dinner table.

Her parents, particularly her father, were very instrumental in shaping
Meredith's negotiation between science and religion. When the conflict between the
scientific conception of evolution and the religious explanation of creation became an
important issue in her World History course, she discussed her conflicting
understandings with her father:

M's father: I tried to get her to see that people make a big mistake when they
try to get science out of the bible. (A 337)

By the time we first broached this issue, Meredith seemed to have fully incorporated
her father's use of the dichotomy between scientific knowledge and religious
knowledge.

Aside from the actual declarative knowledge, Meredith gained from her
family's activities and discussions, it is possible that her mechanistic outlook, her use
of the scientific habit of seeking mechanisms and causality in natural systems, was
gained at home. While it is difficult to establish what determined Meredith's view of nature and biology, the influence of her home activities cannot be discounted.

Meredith's Conceptual Framework for Evolution

Initial framework

Based upon Meredith's use of a strict science/religion dichotomy, there was little interaction between her personal religious beliefs and her conceptions of the scientific explanation for evolutionary changes. Meredith, unlike Stephanie and Tyler, continually used what she understood as the scientific conception for evolution as her own, personal explanation.

Meredith's conceptual framework of evolution used at the outset of the study is demonstrated well by her first concept map. (See Appendix G for Meredith's CM-1, initial.) Meredith's understanding of evolution emphasized the nature of evolutionary changes. She did not refer to the history of evolutionary theory, the scope of the theory, to possible religious conflicts, or the process through which evolutionary changes occur. As discussed for the other participants, Meredith's omission of these topics from her map does not indicate that these topics were not a feature of her conceptual framework for evolution; instead they were not important aspects.

The omission of possible religious conflict is not surprising, as explained by Meredith's use of a strict dichotomy between science and religion. The omission of the process of evolutionary changes is more perplexing, however. Like Brian, Meredith understood nature in terms of cause and effect. It might be expected that this mechanistic world view would promote construction of a conception for process. But when Meredith was questioned directly, "How do evolutionary changes happen?," she responded, "I don't know." (A 49)

Nature of evolutionary change.

As expressed in Meredith's concept map shown above (CM-1, initial), her conceptions of the nature of evolution changes included evolution as (a) a change in
the features of an organism, (b) a change in a group of organisms, (c) a change requiring a very long time period, and (d) a change increasing the group's ability to survive.

The only one of the four conceptions that requires further discussion is her understanding that evolution is a change which increases the group's ability to survive. Meredith understood all evolutionary changes to be directional in order to satisfy the needs of an organism:

M: [Written response in reference to the evolution of blindness in cave salamanders] Cave salamanders, living in a dark environment, did not need to see. Over the years they evolved to lose this unnecessary function. (Pretest # 8)

Her description of all evolutionary changes as the acquisition of beneficial traits or the loss of non-beneficial traits provides no evidence that Meredith recognized the random aspect of evolutionary change. She understood evolution to be a directional, gradual change toward a beneficial trait needed by an organism. However, Meredith's conception of beneficial changed over the course of the initial interviews. In the second interview, she explained that evolution is a species becoming "more advanced." [A 30] While advanced could be used in a vague manner, Meredith understood this term to signify a much more specific meaning:

M: What I mean by more advanced is that ahm, [they become] more suitable for where they live. (A 30)

In later interviews, Meredith used more biologically appropriate terminology to express her understanding of the direction of evolutionary change:

SD: What happens when things evolve?
M: Producing a change to a more fit species. . . .
SD: And what is that?
M: Most able to survive. I guess, you ahm you can just kinda' say the strongest in a sense. . . .
SD: Okay, and is strength and survival, is that related in any way?
M: Yes.
SD: Ahm, how? . . .
M: Strength enables survival and ahm fit increases survival. (A 64-66)
The change in terminology from advanced (suitable) to fittest may be explained by our discussion of the pretest. The pretest contained an exercise in which the student had to select the fittest lion (in biological terms). It appears that this term, fitness, was appropriated by Meredith for use in describing the directionality of evolutionary change. This appropriation occurred in the two weeks that passed between the second and third interviews, and the term was appropriated into Meredith's preexisting conception. However, as the last passage indicates, Meredith used the alternative conception of fitness as being strength.

**Mechanism.**

As mentioned previously, an understanding of the mechanism of evolutionary change was not a major feature of Meredith's conceptual framework. When asked specifically to map her understanding of the process of evolutionary change, Meredith's map closely resembled her first map which described the nature of evolutionary changes. [See Appendix G for the concept map (CM-2, initial.)] Meredith recognized the gap in her understanding:

**SD:** Could you concept map how evolution works?

**M:** That's what I don't know. [Laughter] (A 63)

This lack of knowledge was also shown on Meredith's first hesitant attempts in the sorting task (ST, initial).

While Meredith explained that she had no knowledge of the process of evolution, this was not the case. Structured and open-ended interviews with Meredith revealed her use of several conceptions linked to the process of evolutionary change, but these conceptions differed dramatically from comparable scientific conceptions. Some of these alternative conceptions include: (a) need as causal agent in the origin of variation, (b) the lack of recognition of the importance of variation in a population, (c) natural selection as operating only through the death of unfit individuals, (d) the strength conception of fitness, and (e) the vague conception of the unit of evolutionary change.
The most striking of these alternative conceptions and one which underwent a change in the initial interview period was the conception of need. As demonstrated by her answers to the pretest questions, Meredith understood that new variations were produced in a population because of a need for a beneficial change:

**M:** [Written response in reference to the evolution of speed in cheetahs] Obviously, cheetahs needed to run faster. Perhaps, it was necessary for them to catch their prey and to survive. This occurred because of a need for adaptation. (Pretest # 7)

Meredith's rejection of mutation further signifies the prominence of need in her conceptual framework:

**M:** [Discussing the evolution of webbed feet in ducks] Well, ahm, webbed feet allows, I mean, ah, better, for better swimming. Ah, it was something that ahm, it was an evolved trait wasn't it?

**SD:** Uh, uh. (Yes)

**M:** And, it's not a chance mutation. It was something that was necessary.

**SD:** Okay, so ahm, so how do things evolve?

**M:** Well, ahm, it's mainly as far as when they need to ah adapt to certain conditions. (A 19)

Meredith's use of need as the factor responsible for the production of variation excludes the random aspect of mutation.

But in later questions, Meredith introduced the term "mutation" into her explanation for the production of variation:

**M:** [Reading her answer to a pretest question about the formation of webbed feet in ducks] Ahm, number 4. The population of ducks evolved webbed feet because, [pause] Okay. I, I didn't answer this question. I, I put something in to explain. I said the population of ducks evolved webbed feet because of the need to change to fit the environment. I mean, thus a mutation occurred. . .

**SD:** So what is a mutation? How does that fit into all this?

**M:** It's, it's the change that, ahm, ah, an organism or you can call it an organism goes though to ahm become more suited for the environment that they live in.

**SD:** Ah, ahm, how did, how did that happen? How do mutations happen?

**M:** Ahm, I'm not too sure. (A 21)

Mutation was incorporated into Meredith's pre-existing conception, but this introduction occurred without an understanding of the term. This introduction was
made necessary as Meredith recognized need to be an inappropriate causal mechanism for the production of variation.

M: [Reading her answer to the pretest questions about the evolution of speed in cheetahs] I said that ah, they needed to run faster perhaps it was necessary for them to catch their prey to survive. Ahm, it occurred because of the need for an adaptation. Ahm, I'm really, I'm not sure about that.
SD: Okay, So, like this, try to think out loud. How do you think it would happen? 
M: Ahm, I don't know. I mean, this is that, obviously, I mean, it was necessary. It needed to run faster, but I don't know how this happens. I mean.
SD: Yeah.
M: That's kinda' what you're asking, is how, what causes it and how it happens and I don't know that.
SD: Okay. You don't know.
M: I know it happens. I know it's one answer or something, but I don't know that it is. [Laughter] (A 24-25)

Meredith continued to use need as the ultimate driving force of evolution, but she began to recognize its inability to serve as a mechanism for that change.

Two weeks later, Meredith reflected on the question of the origin of variation (ST, initial):

SD: So how did those rabbits get like that [a brown color]?
M: Ahm, I guess it's some kind of genetic change. I mean, I guess it's [she points to the card depicting DNA].
SD: If you don't, if you don't want to use that card, you don't have to.
M: Oh, yeah, I don't want to use it. (A 69)

This passage demonstrates that Meredith began to recognize that the production of new variation in a population must have a genetic basis. But it is difficult to gauge whether her recognition was something which occurred before the interview, during our discussion, or if it was triggered by the presence of the card depicting a strand of DNA. In any case, this was a relatively new recognition, and at this point Meredith was hesitant in fully incorporating this feature in her explanation of the evolutionary event represented by the sorting task.

Meredith had a conception of natural selection, although she did not use this term to refer to her explanation. During the pretest, Meredith explained that if organisms "aren't well suited for the conditions they live in, they won't make it." (A
20) Natural selection was not a strong component of her understanding of the process of evolutionary change. Her tentative usage of this conception is also signified by her failure to recognize the importance of variation in a population. Meredith demonstrated this alternative conception during the interviews about instances showing a graphic of a litter of kittens (IAI-1, initial):

**SD:** Is it a bad thing to have variation in a litter? Or in a population?

**M:** Yeah, I think it's a good thing, for ahm, nothing to do with. It's something that we like as humans. . . . I think, I think it's good to have variations. But I can't think of what, why I think that.

**SD:** Uh, uh. (Yes)

**M:** But that we should have it there. (A 94)

As discussed in the previous section, the nature of evolutionary changes, Meredith's conceptions of fitness underwent change during the initial interview period. At the outset, Meredith used a collage conception of fitness:

**M:** [Reading her pretest explanation of the fittest lion] Spot fathered a large number of cubs with a large percentage of them surviving to adulthood. Spot is adaptable, as shown by his ability to support himself and move to another location.

**SD:** So what is fitness? What does it mean?

**M:** It's ahm it's being ah, [pause] well-suited for where you live. Being able to you know, provide offspring and be successful in raising young and all that kind of thing. (A 24)

This explanation changed to a more refined and focused conception as shown in the interview one week later:

**SD:** What does fit measure?

**M:** Ability to survive. (A 49)

And this conception again changed in the following week:

**M:** Evolution is a change occurring in a species becoming more fit, resulting in strength.

**SD:** Uh, uh. (Yes)

**M:** And strength enables survival and ah, fit increases survival. (A 66)

The changes described above should not be taken as instances of conceptual change, as Meredith did not appear to be seriously comparing conceptions. Instead, she was searching for a plausible alternative to use in the explanation she was constructing. But the narrowing of scope of the conception is notable. At the outset,
Meredith used all the information at her disposal to determine fitness. In later instances, Meredith equated fitness with survivability, and in the last instance strength was a factor which increased survivability.

The final conception of interest in this group was Meredith's recognition of the unit of evolutionary change. She explained that evolution occurs in a group or organism as opposed to an individual. But it is unclear whether Meredith understood evolutionary changes to include a gradual change in the quality of a trait in an entire population or a gradual change in the percentage of the population with a distinct trait:

SD: So what do you think evolution is?
M: Ahm. [Pause] I just, I think it's just ahm, you know, I don't know much about it. But I just think that it's a change ahm over eons of time that ahm allows ahm a species, usually they become more advanced, you know.
SD: Uh, uh. (Yes)
M: Like in the ape, you know, the man-like ape evolving into man and all that kind of thing. It's just the species becomes more advanced, ahm, more suitable, ahm, that's about all I know about it. (A 30)

All Meredith's explanations of evolutionary changes took this form, so it is difficult to ascertain her conceptions of the unit of evolutionary change. But with need as the most fundamental agent in the production of variation, Meredith had no constraints upon the unit she could select. If need caused variation, entire populations could change incrementally each generation. Another possibility is that at this point, Meredith had not yet considered the appropriate unit, and so this conception did not appear in her interview data.

Human evolution.

It is notable that, unlike the other interview participants, Meredith did not include humans in her answer to the question "What is your personal opinion of the theory of evolution?"

M: Ah, I mean, evolution is, I mean, I definitely believe in evolution. And I think we just have too much evidence for someone not to believe it.
SD: Uh, uh. (Yes)
M: What I'm talking about creationism is that Genesis in the Bible is just saying ahm why, why everything was created and not how. Evolution is how everything was created. (A 27-28)

The omission of humans in her answer may reflect Meredith's personal resolution of the issue of human evolution. From the outset of the study, Meredith understood humans to be the product of evolutionary change. The evidence she recognized as supporting human evolution was found in the similarities between humans and other primates:

M: [In a discussion of gorillas] They have a lot of characteristics of humans. (A 54)

Meredith understood humans to be evolutionarily related to primates, a conception that she felt was strongly reinforced by the animal behavior unit. Despite this recognition, Meredith rejected the classification of humans as primates (IAI-1, initial):

[When shown a graphic of a human boy, a gorilla, and a chimpanzee]
M: All right, two primates and a little boy
SD: Okay, two primates and a little boy. Is the boy a primate?
M: Ahm, no.
SD: No.
M: No. [Laughter]
SD: [Laughter] [Said to tape recorder.] Her face is really screwed up. [Said to M.] You think that's a pretty obvious question? With a pretty obvious answer about primates? Are they animals?
M: Ahm, no.
SD: No.
M: I mean, what, no, we're, we're not animals. (A 116)

Meredith went on to explain that humans were related to animals and related to primates, but "it's such a distant thing" that we could no longer be taxonomically classified in the same manner as primates and animals. (A 117) It should be pointed out that Meredith understood this to be the scientific conception of the classification of humans.

Evolutionary relationships.

Other than human/primate and human/animal relationships, the only other evolutionary lineage that surfaced during the initial interviews was that of dinosaurs/birds. In the interview about instances, when shown a graphic of a heron,
Meredith commented on the recent research that was discussed in class suggesting dinosaurs as the ancestors of birds:

M: I could see, I mean there were some pretty convincing research done on it, but... you know, I don't think I know enough yet to... I mean, I can see how that would, I mean it's very possible. (A 83)

Like Brian and Stephanie, Meredith had begun to apply some of the ideas she had learned in class to her understanding of biological organisms. But unlike the other two, Meredith's comments remained very tentative and noncommittal, as if she were just beginning to investigate the implications and possibilities of this theory.

Species concepts were not an integral feature of Meredith's conception of evolutionary change. While she responded that evolution occurs in groups of organisms, her comments remained very unclear as to the boundaries of this group. When directly asked about species during the interview about instances, Meredith replied with a very informal definition (IAI-1, initial):

[In response to a graphic depicting three different species of bears] SD: So what does it mean to be of a different species?
M: Ahm it's like ahm a different ahm, if. How can I put this into words? Ahm, like ahm, you, they, they produce certain offspring but they're all within the bear, whatever the name of their family is. (A 96)

When questioned further, Meredith explained that each of the three species of bears could successfully interbreed if their ranges overlapped. Her explanations were so unclear that it was difficult to identify the species concept she applied. Meredith's recognition of variation in a species was identified in the earlier section on process, but she failed to recognize the significance of this variation.

Natural history.

Meredith understood animals in terms of their evolutionary adaptations perhaps more strongly than any of the other three participants, as shown in this passage from an interview about instances (IAI-1, initial):

[When shown a graphic depicting an octopus]
M: Okay, we have an octopus.
SD: What can you tell me about octopus-es?...
M: Ahm, well, they, ahm, you know they live in the ocean.
SD: Ah, ah. (Yes)
M: I don't know a whole lot about them.
SD: Do you know what they eat?
M: Probably algae and plankton and. Although that's kind of small. I don't know what they do eat. . .
SD: I think they eat crabs and stuff. What else can you tell me?
M: Ahm, well obviously there is ahm this ahm enables them to ahm best capture you know ah their meal. [She points to the tentacles.]
SD: Uh, uh. (Yes) . . . You say best catch?
M: Well, it makes them more fitted. I mean, if you if maybe they've ahm you know didn't do st-- Ahm you know, like I said a couple of interviews before, I think an organism will die unless they, ahm can be ah a successful predator.
SD: Uh, uh. (Yes)
M: And, ahm, maybe these, ahm if it wasn't like ah you know made up like this. If it didn't have the the legs like this and not the legs but the ahm the ahm it couldn't catch its meal.
SD: Uh, uh. (Yes)
M: I mean.
SD: So you think they're well, pretty well
M: Pretty well adapted.
SD: Yeah.
M: And well suited for, I would think so, I mean it wouldn't be around if it wasn't. (A 87)

This understanding also was evident in Meredith's reaction to the flower graphic. Here she responded in terms of the reproductive function of the flower as well as the energetic expense of the structure. Most similar to Brian, Meredith was easily capable of reacting to biological organisms in terms of the function and evolutionary adaptation of various structures.

Meredith was also notable in terms of her biological vocabulary. She typically used terms such as herbivore, nocturnal, predator, and cross pollination in her responses to the interviews about instances (IAI-1, initial). Like her mechanistic explanations of biological phenomena, the use of such a biological vocabulary may not signify a deeper understanding of the content of biology, but this may be a reflection of her ease in using the forms of discourse accepted in biology classrooms. Meredith may not have known more science than Tyler and Stephanie, but she was familiar with talking science.
Broad evolutionary theories.

Meredith's understanding of the scope of evolutionary theory is not clearly described in her interview data. However, this passage provides some insight into her conceptions:

M: There's [sic] some people who ahm believe that creationism is how the world was created. And so they ahm, they don't believe. Like some, I think there are a lot of, people that they want to believe that, that's what Genesis was explaining, how everything was created. They wouldn't believe in evolution. (A 28)

Meredith understood scientific evolutionary theory to encompass the explanation for the creation of the earth as well as subsequent changes in species. It is notable, however, that Meredith never broached this topic in our open-ended interviews. This may be a reflection of Meredith's approach to biology. Meredith the pragmatist dealt only with issues of immediate concern (i.e., issues I introduced). She seldom identified areas of difficulty herself.

As described previously, Meredith applied very little of her biological knowledge outside of the classroom. Because of this, she understood the importance of evolution to be limited to the theoretical considerations of biological topics. But within this realm, Meredith was articulate about the applications of evolutionary knowledge:

M: I think that when you're, that when you're doing, running experiments, and you're you know concerned with animals and plans and all
SD: Uh, uh. (Yes)
M: that kind of thing, that you, you have to consider evolution. But that it's not necess--I wouldn't say that it's necessarily more or less important [than some other biological theory].
SD: Okay.
M: I think it's just something, it's off to itself and it's something that needs to be considered when doing
SD: Okay.
M: things. It's an additional bit of information that you consider when you look at plants or animals. (A 154-154)

Meredith understood evolution to be a common thread running throughout biology which provided additional information about any biological phenomenon. However,
she did not recognize the relative importance of the theory. At this point in the year, Meredith understood evolution to be informative but unimportant:

**M:** I mean, I think it helps you, that you understand evolution, but not everything that you do in biology requires that you have an understanding. (A 156)

**Evidence for evolution.**

Evidence supporting or refuting evolutionary theory was not a prominent aspect of Meredith's conceptual framework for evolution. Like each of the other participants, Meredith recognized fossil evidence as the most important form of evidence supporting evolution. Meredith also cited similarities between humans and primates as another importance piece of evidence supporting the theory of evolution. However, Meredith's acceptance of evolution theory was so complete that she could not identify any type of evidence that contradicted evolution.

**Other biological knowledge.**

Like each of the other interview participants, Meredith was familiar with the genetic basis of inherited traits. This conception was first revealed in the sorting task (ST, initial) and was further elaborated on during the prediction interviews. In the prediction interviews, Meredith was found to consistently apply the Mendelian conception of independently assorting traits. She also introduced the conception of sexual dimorphism into her predictions. She used the conception of sexual dimorphism to predict the inheritance of color in a clutch of ducks, and she accompanied her explanation for this prediction with an example from nature:

**M:** Ahm, well, I think that, that if the, the ahm, if the male is gonna' be black like this one and the female will be like this one [she points to the white duck on the card].
**SD:** Uh, uh. (Yes)
**M:** If they meet. I don't think it's gonna' be a blend of the two of them you know. It's gonna', if it's a male it will grow the black, dark feathers. And
**SD:** Uh, uh. (Yes)
**M:** And the female will grow the white feathers. It's kinda' like the you know, the cardinal. The same kind of thing.
**SD:** Do you think ahm. Okay. Let's see. Tell me about cardinals.
M: The males are the bright vibrant color and the female is kinda' dull looking. I think, you know, I think they're the same species and everything. Kinda' like the ducks. (A 135)

Other aspects of Meredith's biological knowledge included her familiarity with animal taxonomy. She often applied this knowledge in the interviews about instances (IAI-1, initial). Like each of the other interview participants, Meredith was able to categorize animals into their appropriate higher level taxa, although often she was not able to provide a justification for this classification.

[In response to a graphic depicting a young sea turtle on sand]
SD: Can you tell me anything about turtles? [Pause]
SD: Any neat things about them. What do you know about them?
M: Ahm. [Laughter]
SD: Are they amphibians? Are they reptiles? Are they mammals? Birds?
M: No. [Laughter] Ahm, do they fall under reptiles?
SD: Yeah.
SD: Uh, uh. (Yes) Do you think, . . . , what makes you think it's a reptile? Why we would put it into the reptile?
M: It has something to do with, you know, I don't know what the different, the reasons why
SD: Uh, uh. (Yes)
M: I can just, generally if you know if I see something that I can say you know.
SD: Okay.
M: I can't necessarily tell you all the things that make it. (A 110-111)

The final aspect of Meredith's biological knowledge was her understanding of a competitive natural world. When shown a graphic of an elephant reaching into a tree in order to eat from the branches, she remarked (IAI-1, initial):

M: The, ahm those elephants are competing for food.
SD: Uh, uh. (Yes)
M: and the, one some of 'em, of course they won't, probably won't, might not survive. (A 89)

Historical aspects of the theory.

During the initial interviews, Meredith made no mention of the history of the development of evolutionary theory. As has been mentioned previously, this omission should not be taken as a lack of knowledge, but should be understood to signify the
relative lack of importance Meredith placed on this aspect of her conceptual framework for evolution.

See Figure 19 for a summary of Meredith's initial conceptual framework for evolution.

<table>
<thead>
<tr>
<th>Human Evolution</th>
<th>Characteristics of Evolutionary Changes</th>
<th>Evolutionary Metatheories</th>
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<tbody>
<tr>
<td>Humans evolve</td>
<td>Long time is required</td>
<td>Evolution includes creation of life and changes since primordial soup</td>
</tr>
<tr>
<td>Humans are separate from primates and other animals</td>
<td>Evolution is a gradual drive toward a beneficial trait</td>
<td>Evolution is not essential in biology</td>
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<tr>
<th>Evidence for Evolution</th>
<th>Evolutionary Relationships</th>
<th>Historical Aspects of Theory</th>
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<tr>
<td>Fossil are supporting evidence</td>
<td>Populational and typological species concept</td>
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<tr>
<td>Similarities between humans and primates are supporting evidence</td>
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<thead>
<tr>
<th>Related Biological Knowledge</th>
<th>Mechanism</th>
<th>Natural History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mendelian genetics</td>
<td>Need as origin of variation</td>
<td>Much knowledge of recent natural history of animals</td>
</tr>
<tr>
<td>Nature is competitive</td>
<td>No importance placed on variation in a species</td>
<td>Old, changing earth</td>
</tr>
<tr>
<td></td>
<td>Vague conception of unit of evolutionary change</td>
<td>Knowledge of animal taxonomy on broad scales</td>
</tr>
<tr>
<td></td>
<td>Strength concept for fitness</td>
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</tbody>
</table>

Note. Italics indicate instances of conceptual change. Solid block indicates academic conception.

Figure 19
Summary of Meredith's initial conceptual framework for evolution

Mid-year framework

Nature of evolutionary changes:

While some aspects of Meredith's conception of the nature of evolutionary changes remained intact during the mid-year period, other aspects were first documented during this period, and still others underwent conceptual change.

Conceptions which remained intact included evolution as (a) a change in the features of
an organism, (b) a change occurring in a group of organisms, and (c) a change requiring a very long period of time.

Several different conceptions surfaced during this mid-year period. This group of conceptions do not represent a conceptual change from the initial period, instead these conceptions could have been a pre-existing feature of Meredith's conceptual framework which were not measured in the initial period. The first of this group is Meredith's conception of evolution as a continuous process. During an open-ended interview, Meredith explained that evolution occurs at all times within all groups of organisms, including humans.

During this period it also became evident that Meredith understood evolution as a series of gradually occurring, subtle changes that cause vertical alterations within a single group of organisms. When she was shown three graphics depicting different phylogenetic trees, (a) evolution shown as a change of color within a group of butterflies, (b) evolution as a change leading to the creation of several vertebrate groups, and (c) evolution as a set of vertical changes within a group of armadillos, Meredith picked the vertical changes shown in (c) as best representing the process of evolution. (IAI-2, mid-year). This selection was based on Meredith's rejection of evolution as change resulting in differentiation within a species, as she understood to be represented by the color change in the butterflies. She also rejected the characterization of evolution as a series of wide, drastic changes which produced radically different taxa, as she explained was represented by the graphic depicting several vertebrate groups. Instead, Meredith explained that evolution:

M: It's not a drastic process. It's more of a subtle thing. So you don't really notice what's going on. It takes so many, you know, eons of time. (A 243)

The mid-year interviews also revealed that Meredith understood evolution to be a basically unplanned process that results in changes, "It's always occurring but it's nothing that's planned to happen this way." (A 183) While she denied that evolution
was planned, she used the conception that the process was predictable. When she explained that given constant environmental conditions, the changes that result from evolution could be predicted, Meredith signified her conception of evolution as process bound by environmental conditions. At this point, Meredith seemed to have no recognition of the random aspect of evolution.

Meredith's conception of evolution as a fundamentally predictable process underwent a subtle change as reflected in an interview just one week later:

**M:** I think every--A lot of things have a something, you know a random component to 'em.

**SD:** Uh, uh. (Yes)

**M:** and it's not necessarily always one way. And no--nothing is gonna’ occur the same way each time. . . .

**SD:** So do you see change as being a big part of evolution through natural selection?

**M:** Well, I guess chance in the sense that ahm, you know, depends on what the, kinda’ what the environment is like and . . . and some of those things I guess can happen by chance.

**SD:** Okay.

**M:** Not planned out that this is gonna’ happen that way. (A 194-195)

Meredith continued to understand evolution was inextricable from environmental changes, but she now explained that these environmental factors were a source of randomness and unpredictability for the process. In an interview conducted three weeks later, Meredith's conception of randomness changed again. This change is seen in the following passage, as Meredith explained her selection of the term random in the word sort (WS, mid-year):

**M:** Yeah, keep random [on the evolution side of the sorting table]. Because you have ahm, I guess it refers, referring to the ahm mutations or whatever or the, the changes that occur. That you know, that cause evolution.

**SD:** Okay.

**M:** And it's not something ordered. It's not planned to be that way. (A 243)

Later she placed the term chance beside random:

**M:** Chance. . . . I'd probably just, I'd probably leave that because it's ahm you know, it's by chance that these ahm mutations occur. (A 244)
Initially, Meredith understood evolution to be a directed, predictable process. But in this mid-year period, Meredith began to recognize the random aspect of evolutionary changes. This recognition was first introduced through the unpredictability of environmental conditions which she understood to control the direction of evolutionary change. In this last interview for this mid-year period, Meredith maintained this recognition, but she understood the random component to stem from mutations and not environmental factors.

It is notable that Meredith first recognized the random aspect of evolution during the same interval that she first rejected need as a controlling component of evolutionary change. She was not outspoken concerning the rationale behind this rejection, simply commenting, "Need. I don't know. I really don't see how that fits in (to evolution)." (A 244) Again, it is difficult to determine the causality behind these changes. But it is noteworthy that the two logically competing conceptions of evolution, need driven and random based, underwent diametrically opposed changes during the same time period. Meredith's tentative recognition of the random aspect of evolution was also accompanied by a change in her understanding of evolutionary mechanisms which will be described in the next section.

Another conception that underwent subtle changes included Meredith's understanding of the end product of evolution. While previously she understood evolution to be a directional change toward a beneficial trait, during the mid-year period Meredith explained that evolution was driven toward the "specialization" of a group of organisms. (A 180) However, she continued to understand the overall result of any evolutionary change to increase the success of a species. Her conception of success continued to be defined by the group's ability to survive over a long period of time.
Mechanism.

The most remarkable instances of conceptual change that occurred in the mid-year period were found in the group of conceptions describing the mechanism of evolutionary change. At the outset of the study, Meredith's conceptions in this group were a muted aspect of her conceptual framework. This situation radically altered during the mid-year period. Toward the end of this interval, Meredith easily applied many scientific explanations for the process through which evolution operates. Not surprisingly, this conceptual restructuring accompanied her changing conceptions of the nature of evolutionary modifications. But some aspects of her conceptual framework for this group of conceptions were retained. These more static conceptions included her lack of recognition of the importance of the variation in a population and her strength conception of fitness.

The most striking example of conceptual change was found in Meredith's understanding of the origin of variation. This conception changed tentatively as she began to recognize that need could not be a viable mechanism of evolutionary change. After this initial recognition, she referred to mutations as the origin of variation, but this was a tentative usage of the conception as she had no actual understanding of mutations. Her responses for the sorting task conducted at the end of this interview period signified her incorporation of this conception as she discussed that the origin of variation must have included some sort of genetic change.

Related to her changing conception of need, Meredith's conception of mutation also underwent a significant change. She began to use mutation as a central component of her understanding of the process of evolution. Her concept map constructed during this period features mutations on the second row of the hierarchy (CM-2, mid-year). During our discussion of this map, she explained:

SD: Do you see mutation as an important part of evolution?
M: Yeah.
SD: Why?
M: Because it's the whole thing that, that ahm, I mean you couldn't have evolution if you didn't have a mutation that produced the variation. (A 229)

She also used this conception in her explanation of the evolutionary change shown in her journal entry for artifact 5 and in the sorting task (ST, mid-year):

SD: How did those rabbits get there? These brown ones?
M: There was a mutation. (A 233)

(See Appendix G for CM-2, mid-year.)

As this conception was being more firmly incorporated into her framework for the process of evolutionary change, Meredith's conception of mutation became more differentiated. During this period, she described mutations as genetic changes that could be both harmful and beneficial.

SD: Do you know what caused those mutations?
M: It's just ahm, I think, by change that happens. (A 230)

In the word sort conducted in the mid-year period, she explained (ST, mid-year):

M: Change? Ahm, I'd probably just, I'd probably leave that because it's ahm, you know, it's by chance that these ahm mutations occur. (A 244)

However, while she could explain the random component of mutations in response to direct questions, Meredith had difficulty applying this conception to a biological phenomena. When discussing the bear mutations graphic, Meredith explained that the only possible mutation was that providing longer hair length (PI-1, mid-year).

M: Well since the, the ahm, the temperatures are becoming colder it is not ahm you're not gonna' have something losing, losing its hair. That would not be a beneficial mutation. (A 245)

While Meredith could describe mutations as random events, she also explained that only beneficial mutations were probable. This conflict signifies that conceptual change was not yet complete. While she had made some connections, she had not yet begun to apply this changing conception.

Accompanying her construction of a random process for the origin of variation, Meredith had begun to separate the actions of natural selection from the origin of variation.
M: Natural selection increases the individuals of a population with a trait. (A 228)

This passage also demonstrates that Meredith used the scientific conception of the unit of evolutionary change to be the percentage of the population with a trait.

As has been shown, Meredith's conceptual system for the process of evolutionary change underwent radical changes toward a scientific understanding. It is important to note that this change accompanied very similar changes in her conception of the nature of evolutionary change. Such conceptual change would be expected due to Meredith's mechanistic approach to scientific knowledge. Meredith recognized the gains she made during this period and we discussed this:

SD: Where did you learn all this?
M: [Laughter] I don't know.
SD: Uh, uh. (Yes)
M: I love it. Ahm, a lot of it, a lot of stuff I knew. But for me to have to sit down and then rattle it all out,
SD: Uh, uh. (Yes)
M: I don't do very well.
SD: Uh, uh. (Yes)
M: It's ahm sometimes it takes me, I have to stop and think about it, you know? I don't know. We really haven't, all we've done on it is read that article.
SD: The article, that one on the new synthesis--that article?
M: Uh, uh. (Yes) (A 228)

Natural history.

In our discussions of the geological history of the earth, Meredith described a very old, changing earth. She explained that the earth was "billions of years old," and that life was created long after the first creation of the earth. (A 170) After that time, the continents had drifted, the climates had changed, and species underwent evolution. She understood humans to have been present only in the last 7,000 years. In the time line she drew depicting the history of life on earth, Meredith included, in this order, the origins of: (a) the earth, (b) "microorganisms such as bacteria and protozoa," (c) shellfish, (d) amphibians, (e) mammals, and (e) humans. After she drew the time line, Meredith laughingly explained, "I've got some gaps in my knowledge here.” (A 189)
Like Brian in her understandings of natural history, Meredith did not focus solely on the creation of humans. Instead, she recognized that many events occurred before humans evolved.

Other biological knowledge.

In our discussions of intentionality in nature, Meredith was explicit in her rejection of anthropomorphic explanations for the actions of organisms and natural processes. However, she used a sophisticated understanding of this conception in which she did not reject the possibly of thought in any organism. When more advanced vertebrates were discussed, she explained that these organism were capable of thought and planning. She explained that a beaver was "probably intentional" when building a lodge and a prairie dog could learn to open a nut. (A 195)

Another conception which was revealed in the mid-year period had to do with Meredith's conception of the process of the inheritance of physical traits. Like her previous conceptions of the nature of the evolutionary process, she viewed inheritance as fundamentally a very ordered process. She demonstrated no recognition of the randomness of the process of meiosis and the subsequent variation it introduced.

Other aspects of Meredith's conceptual framework for evolution, including her conceptions of human evolution, evidence for evolution, evolutionary relationships, broad evolutionary theories, and the historical aspects of evolutionary theory underwent no changes in the mid-year period.

See Figure 20 for a summary of Meredith's mid-year conceptual framework.

Year-end framework

By the last interview it became evident to both of us that Meredith had learned a great deal about evolutionary theory during the school year. We discussed the possible reasons for this:

M: Like whenever we've talked about it in class I probably paid more attention than you know ahm, I've paid careful attention because you know, it's something that we're talking about each week.
SD: Uh, uh. (Yes)
M: And, you know, it's something that I'm interested in, you know? Wondering, wondering why and how and whatever. I think that maybe if we hadn't been doing this I wouldn't have been, you know, trying to find out or whatever. Just tune into it in class. (A 316)

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**Evidence for Evolution**
- Fossil are supporting evidence*
- Similarities between humans and primates are supporting evidence*

**Related Biological Knowledge**
- Mendelian genetics*
- Nature is competitive*
- Genetic inheritance is a ordered process
- Rejection of anthropomorphism

**Evolutionary Relationships**
- Populational and typological species concept*

**Mechanism**
- *Mutations as origin of genetic variation*
- No importance placed on variation in a species*
- Vague conception of unit of evolutionary change*
- *Natural selection operates through differential reproduction*
- Strength concept for fitness*

**Natural History**
- Much knowledge of recent natural history of animals*
- Old, changing earth*
- Knowledge of animal taxonomy for larger taxa*

Note. Italics indicate instances of conceptual change.
* indicates retention of conception from previous description.
Solid block indicates academic conception.

Figure 20
Summary of Meredith's mid-year conceptual framework for evolution

**Mechanism.**

The greatest gains made by Meredith were found in her conceptions of the process of evolutionary change as signified by Meredith's last concept map. (See
knowledge of the nature of evolutionary change, this map revolved around her understanding of the process of evolutionary change. During the year, Meredith constructed a system of conceptions for evolution which were largely scientific, although several minor alternative conceptions did remain. Conceptions for her understanding of process that were retained include: (a) mutations as the source of variation, (b) a separation of the action of natural selection and the origin of variation, and (c) a lack of recognition of the importance of variation in a population.

There were some interesting components of Meredith's conception of mutation. As was seen during the mid-year period, Meredith had an unresolved understanding of the nature of mutations. While she could formally describe mutations as random events, this understanding was not applied in the interviews about instances about a mutation event in a hypothetical population of bears. When her conflicting answers were brought to her attention, Meredith was unable to recognize the conflict:

SD: When you first saw [the mutation graphic], you said, okay, he could become hairy because of a gene mutation. Ah, the burrowing, thought, is probably explained.
M: Well, I said you couldn't do that because of ice. You can't.
SD: Yeah?
M: Burrow in that.
SD: Okay, and you said [losing hair] is a mutation that wouldn't happen.
M: Right. Because that wouldn't be beneficial.
SD: Okay. Ahm, I'm gonna ask you something to see ahm if you recognize anything. Earlier the same time, the same day, we had talked about how mutations are random events.
M: Uh, uh. (Yes)
SD: And you described them that way. Do you see any conflicts between your answer on this bear question and the idea that mutations are random events?
M: No. I, I don't see why that would be, why that couldn't, why this [pointing to the long hair mutation] couldn't be random. (A 252)

Faced with logically conflicting responses, Meredith could not recognize the inconsistency.

The discussion shown above occurred during the initial interview of the year-end period. In an interview two weeks later, Meredith explicitly discussed the varied nature of mutations during the construction of her concept map:
M: Well I want to say that ah, ah, beneficial ah, you know, you have both non beneficial and beneficial mutations. But it's the ones that are beneficial that will be successful. (A 298)

This passage signifies that her the random aspect of mutation was further incorporated into her understanding of the process of evolution.

Meredith's incorporation of mutation into her understanding of the process of evolutionary changes is also signified by her understanding of the production of adaptation through mutations:

SD: How does that happen, that birds' beaks are kinda suited to their, what food they eat?
M: It's just that ahm, mutation once again . . .
SD: So what is an adaptation?
M: It's just ahm when an animal becomes ahm, changes to be most suited for its environment.
SD: Uh, uh. (Yes) And ahm, how is that related ahm to mutation?
M: Because ahm, mutations are changes and ahm those changes will reproduce to produce animals that are, that are better suited for their environment, better adapted. (A 264)

While Meredith used many scientific conceptions in her understanding of evolutionary change, she retained some alternative conceptions. On the posttest, Meredith explained that evolutionary changes include a small increase in the quality of a trait but only within a percentage of the population. This conception represents a blend of scientific and alternative conceptions. While she understood that mutations would occur and be passed down through an increase in the proportion of the population, she also understood evolutionary changes to be an accretion of small mutation events.

Another alternative conception used by Meredith at the conclusion of the study involved her conception of fitness. While this conception had been undergoing slight changes throughout the study, at year-end, Meredith used the common alternative conception of fitness to involve "adaptability:"

M: I think Spot is ah, the fittest because ah, he's, he's able to ah, you know, he seems pretty adaptable. (A 314)
The final important aspect of Meredith's conceptual framework for evolutionary processes was seen in her written answers for the posttest. While her use of a largely scientific understanding of evolution change was evident in our interviews, this conceptual framework was not demonstrated in her written answers:

**M:** [A written response regarding the evolution of speed in cheetahs] Well I guess it was necessary for the cheetahs to run this fast in order to catch their prey. At 20mph, they were not successful at this. (Posttest #7)

**M:** [A written response regarding the evolution of blindness in cave salamanders] After living in a cave for a period of time, eyes would serve no function any longer. These salamanders evolved in such as way to "get rid of" this nonfunctional feature. (Posttest 8)

In our interview about this test, she expanded a great deal on the salamander question:

**M:** You know, you'd have a mutation but after you ah live in a cave for a period of time and ahm ah eyes don't serve any function.

**SD:** Uh, uh. (Yes)

**M:** They're no longer needed and so if there is a mutation that produces blindness in the salamanders then that's, you know, that certainly, you know, isn't necessary. It, it would do away with the function that's not needed and so it doesn't hurt the salamanders

**SD:** Uh, uh. (Yes)

**M:** That have that mutation. (A 315)

It is evident that Meredith's written answers do not reflect what she knew of the process of evolutionary change. The difference between students' conceptions and their written statements has been documented in past research in this area (Brumby, 1984; Halldén, 1988).

**Nature of evolutionary change.**

All aspects of Meredith's conceptual system for the nature of evolutionary changes were retained. However, there was growth in her knowledge of adaptations. As was discussed in the preceding section, Meredith had begun to successfully link the process of mutation to the production of adaptations in an organism. She began to understand adaptation as a means of becoming "better suited" for a particular environment. (A 264) She further explained that a long time span is required for an adaptation to become firmly lodged in a population. While she did make significant changes in her conception of adaptation, Meredith's conception of adaptation remained
very broad in its scope. She linked adaptations to mutations, but she did not recognize all adaptations as having a genetic basis, instead referring to any changes by an organism to fit its environment as being adaptations. She could not differentiate between the fundamentally different processes of behavioral changes, physiological changes, and evolutionary changes within a population.

_Meredith's undefined species concept was retained through the end of the year._

This species conception is congruent with her continued failure to recognize the importance of variation in a population:

_SD:_ So ah, do you think it's good or bad for litters like these kitties to be different colors and sizes like that?

_M:_ Ahm.

_SD:_ Could there be any benefits or any ahm

_M:_ I can't think of any offhand. I just know that it's good to have variation but I don't know why. (A 262)

_Her conception of variation in a species is difficult to align with her conception of a species as a group with similar characteristics. This recognition of the presence of variation precludes her species concept from being labeled typological, but her failure to understand the importance of variation precludes her species concept from being labeled as populational in its origins. Instead her species concept remained as an alternative amalgam of these two conceptions._

_Broad evolutionary theories._

_Meredith summed up her understanding of the application of this evolutionary theory on her final exam:_

_M:_ Evolution is also considered a major theory in Biology. It is a powerful one that seeks to explain why organisms have the particular traits that they have. This theory is a reasonable one as to how life has changed over geological time. (Artifact 7, #1)

This answer reflects two aspects of her knowledge of the broad applications of evolution. The first is that she considered evolution as a means for understanding organisms' adaptations, a conception that she had held throughout the study. The
second concerned her conception of the scope of this theory. At year end, she understood evolution to involve only the changes that occur within organisms and not the initial creation of the earth or life.

Other aspects of her conceptual ecology, including her knowledge of natural history, human evolution, historical aspects of evolutionary theory, other biological knowledge, and the evidence she accepted for evolution theory, were retained unchanged during the year-end interview period.

See Figure 21 for a summary of Meredith's year-end conceptual framework.

Summary of year long conceptual change

Meredith had achieved what Tyler strived for, establishment of a useful separation of scientific and religious knowledge. Because of this, the issue of evolution was not an emotional topic for Meredith. In this regard Meredith was similar to Brian, although she did not value scientific knowledge to the same degree. It is significant to note that Meredith accepted the plausibility of evolutionary theory long before she understood it. Like the students described by Lawson and Weser (1990), and similar to Tyler, Meredith had judged the theory based on sociological considerations and not logical coherence. Despite this difficult beginning, Meredith experienced profound conceptual change toward a scientific conceptual framework for evolution during the course of the study. Most significant of these changes is her knowledge of the nature and process of evolutionary changes.

Summary of the Four Participants' Conceptual Change in Evolution

The following section will summarize the participants' conceptual frameworks as well the conceptual change they experienced in relation to their personal characteristics. The applications these findings have for the conceptual change theory will be further described in Chapter 7.
Culture, Conceptual Ecologies, and Conceptual Change

From the outset of the study, Hurston and I selected specific student participants in order to provide the maximum variation in personal characteristics in

<table>
<thead>
<tr>
<th>Human Evolution</th>
<th>Characteristics of Evolutionary Changes</th>
<th>Evolutionary Metatheories</th>
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</thead>
<tbody>
<tr>
<td>Humans evolve*</td>
<td>Evolution is a continuous process of small changes within a group</td>
<td>Evolution includes creation of life and changes since primordial soup*</td>
</tr>
<tr>
<td>Humans separate from primates and other animals*</td>
<td>Long time is required*</td>
<td>Evolution is not essential in biology*</td>
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<tr>
<th>Evidence for Evolution</th>
<th>Historical Aspects of Theory</th>
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<tr>
<td>Fossil are supporting evidence*</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>Genetic inheritance is a ordered process</td>
<td>Evolution is unplanned but predictable</td>
<td>Knowledge of animal taxonomy for larger taxa*</td>
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<td>Rejection of anthropomorphism</td>
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<th>Mechanism</th>
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<td><em>Mutations as origin of genetic variation</em></td>
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<td>Natural selection operates through differential reproduction*</td>
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<tr>
<td>Strength concept for fitness*</td>
<td></td>
</tr>
</tbody>
</table>

Note. Italics indicate instances of conceptual change. * indicates retention of conception from previous description. Solid block indicates academic conception.

Figure 21
Summary of Meredith's year-end conceptual framework for evolution

an effort to better understand the process of conceptual change. However, the four participants were shaped by the culture of the biology class and so they shared some important personal characteristics. Each of the four participants accepted the importance of academic knowledge and expected that this knowledge would be meaningful. This disposition to the formal knowledge of school was also reflected in
the culture of the classroom as evidenced by the theme of Talking Academic. A favorable academic orientation may have played a very significant role in the conceptual change which occurred, although this study's design prohibited pursuit of this line of investigation (as will be further discussed in Chapter 7).

The conceptual ecologies of the four interview participants differed markedly in terms of their conceptual frameworks, epistemological commitments, scientific and religious orientations, and acceptance of evolution theory. Because of these differences, the conceptual change experienced by these four participants offers insight into the actions of a learner's conceptual ecology on the process of knowledge restructuring.

**Brian--Biologist as Scientific Theorist**

Brian's approach to biology can best be expressed as "Biologist as Scientific Theorist." This label is used to signify his deeply held, favorable scientific orientation and his realist epistemological approach to scientific knowledge. Typically, Brian searched for an overview of what was being discussed soon after he constructed a basic understanding of the physical phenomenon. His consideration of any natural phenomena took that pattern of searching for any possible theory to describe the physical causality, understanding the operation of the mechanism, logical assessment of rival theories and their applications, and logical selection of the single most probable explanation. While Brian did not interpret his personal life or knowledge through a religious framework, neither did he reject the existence of a "greater being." He explained that conflicts that resulted from the overlap of scientific and religious knowledge were necessary for the advancement of the boundaries of what scientists understand. From the outset of our study, Brian understood that scientific truths must be independent of religious assumptions and he used a non-theistic approach to evolution (Nelson, 1986). From the beginning of the
study Brian displayed no conflicts in what he understood about evolutionary theory and what he believed.

Brian's scientific orientation is evidenced in his early conceptual framework for evolution. In the beginning of the study, a scientific understanding of the mechanism of evolutionary change was central to his framework. As the study progressed, this basic scientific understanding was refined and in his last few interviews he used a sophisticated understanding of biological adaptation, the view of the random aspect of mutations operating within biological controls, and the differential reproduction aspect of natural selection. He approached evolution as he did many topics and his foundational understanding evidenced at the beginning changed into a more holistic view of evolution as he considered the mechanisms, the patterns formed by these mechanisms, and the various theories which explicate facets of this theoretical framework.

At the close of the study, Brian used the most scientifically appropriate framework for evolution of any of the four participants. The foundation of much of this framework was in place from the beginning. However, Brian's strong scientific orientation negated many of the conflicts the other participants experienced. This orientation allowed him to focus on select areas of conceptual difficulties. Brian was not attempting to determine all the possible theoretical alternatives for a phenomenon; instead he was looking for the most scientifically appropriate alternative. Because Brian's epistemology followed traditional scientific lines, his conceptual change was linear, logical, and predictable.

Stephanie—Biologist as Multidisciplinary Realist

Stephanie's approach to biology can best be expressed as "Biologist as Multidisciplinary Realist." With an appreciation for many disciplines such as literature, philosophy, science, and world religions, she often changed the context through which she understood natural phenomena. Multiple interviews and interview
techniques indicated that Stephanie could use an assortment of approaches to understand any biological topic. One week she would explain evolutionary theory from a social-cultural perspective. The next week she could approach the same material with a scientific, mechanistic approach. However, Stephanie rejected using a relativist label to describe herself because she continually referred to the natural world for confirmation of her conceptions. Based on this, I refer to Stephanie as a multidisciplinary realist because she needed to use the knowledge of many disciplines and ways of knowing in order to construct her understanding of reality.

The strength of Stephanie's religious orientation is another important feature of her conceptual ecology. She understood life to have a fundamental theistic component. At the outset of the study, Stephanie's rejection of the existence of wide-scale evolution was in part based on her theistic beliefs and in part based on her perception of the implausibility of the mechanism. Instead, she understood evolution in progressive creationist terms and she understood only slight changes to occur within groups of organisms. This situation became more complex as we consider Stephanie's strong interest in anthropology that made her keenly interested in such questions. Based upon these diverse interests, Stephanie experienced a great deal of conflict in trying to negotiate the intersection of her religious beliefs and her scientific knowledge. However, one characteristic of her fluid epistemological stance was that it allowed her to recognize attributes of theories that she did not personally accept. Coupled with this, Stephanie enjoyed the exercise of intellectual debate, and so she enjoyed the inherent ambiguity of her epistemological position.

At the outset of the study, Stephanie used many alternative conceptions in her understanding of the evolutionary change accepted by science. She understood science to describe drastic wholesale changes between groups of organisms driven by Lamarckian forces. She personally rejected these conceptions. Stephanie's strong
religious and anthropological interest formed the basis of her early frameworks and these were the lenses she most frequently used to understand evolutionary issues.

During the scope of the study, Stephanie's understanding of evolutionary mechanisms underwent drastic changes and she was capable of applying sophisticated scientific explanations for the mechanisms and implications of evolutionary theory, much like Brian, by the end of the study. While she continued to accept the existence of only small-scale changes within groups even at the end of the study, what she took to be "small scale" and "within a group" underwent drastic changes. By the end of the study, Stephanie accepted as fact many many instances of biological evolution. However, her interest in human evolution and the religious implications of such changes remained a focal point of her conceptual framework.

Stephanie's conceptual change is of particular interest because of her lack of a wholesale scientific focus. In Stephanie we can see pattern for the resolution of conflicts caused by opposing knowledge frameworks. While Stephanie was largely successful in constructing a scientific framework for the mechanism of evolutionary change, this change was accomplished without a corresponding change in belief. Thus, under specific conditions, it is clear a student can learn topics which she/he does not believe using a religious framework. However, aspects of Stephanie's conceptual ecology may have had her uniquely suited to this situation. Her multidisciplinary perspective made her keenly interested in many knowledge claims. With Stephanie, we also see other aspects of a learner's conceptual ecology in play. For Stephanie, portions of evolutionary theory had to be validated because of her strong anthropological interest. Stephanie's case demonstrates that conceptual change does not always follow traditional logical patterns, but can remain within the bounds of rationality.
Tyler—Biologist as Authority Seeker

Tyler's approach to all academic topics, including biology, can best be termed "authority seeker." This label reflects the end result of many of her academic endeavors. Tyler often compartmentalized her knowledge. When this compartmentalization broke down, such as during the process of classroom activities, discussions, or simple conversations, Tyler was thrown into conflict as she attempted to reconcile competing knowledge claims. Tyler then would seek knowledge from an authority figure in order to negotiate this conflict. This situation was complicated by her epistemological understanding of science as a body of static, sure knowledge. Taken together these characteristics made Tyler the most unsure of all the participants. Tyler's religious orientation coupled with her personal insecurity created a great deal of anxiety for Tyler during the scope of the study. While she articulated a partial resolution of science-religion conflict regarding evolution and used a theistic understanding of the process of gradual creation, she continued to be uncomfortable with this tension (Nelson, 1986).

Tyler was interested in science but she did not use a mechanistic understanding of the natural world. Instead, she understood the natural world in terms of aesthetics. Tyler's aesthetic view of the natural world is reflected in her conceptual framework at the outset of the study. She did not view organisms in mechanistic terms but in terms of aesthetic qualities such as beauty, order, and symmetry. Her early conceptual framework for evolution was dominated by a vague description of the patterns of evolutionary changes and revolved around the issue of human evolution. Within her aesthetic approach to the topic, Tyler used many alternative conceptions to describe evolutionary patterns. When pressed, she hesitantly offered several alternative conceptions of the mechanisms of such a change. So while Tyler was capable of mechanistic thought, this was not her first approach to a biological topic.
Tyler's case study provides valuable insight as it is compared to Stephanie's. Like Stephanie, Tyler entered the study as using a progressive creationist approach to evolution, although for Tyler this was an issue filled with anxiety as her own understandings conflicted with those of science. During the course of the study, Tyler constructed a partial resolution of this perceived conflict through an acceptance of human speciation and a personal rejection of the special creation of humans. Thus, during the study, Tyler shifted from a progressive creationist approach to a tentative application of theistic evolution. However, her focal point of human speciation was retained throughout the school year.

Accompanying the shift in her conceptual ecology, Tyler also experienced conceptual change toward the scientific explanation of evolutionary change. However, Tyler's year-end conceptual framework could not be considered completely scientific. Unlike Brian, Tyler was not searching for the single most plausible answer and she continued to use dual constructions to explain a single phenomenon. Additionally, Tyler had little understanding of the competitive aspects of natural systems and many of her scientific conceptions for the mechanism of evolutionary change had little logical basis. Due to Tyler's aesthetic orientation and unquestioning reliance on authority, much of her conceptual change was fragmentary, discontinuant, and extra-logical.

Meredith—Biologist as Pragmatist

Meredith's approach to biology can best be expressed as "Biologist as Pragmatist." This label signifies Meredith's tendency to value only topics that she understood as having a practical importance in her education. She valued knowledge for "education sake" but understood much of her classroom knowledge to have little personal importance. Unlike Brian and Stephanie, Meredith related to knowledge only as it was presented in the classroom and she did not attempt to relate one theory to another on her own. Although she was religious, Meredith had pragmatically
achieved a successful negotiation of the science-religion conflict through the consistent use of a strict dichotomy separating the two forms of knowledge. Using this dichotomy, she accepted evolutionary theory. Meredith used a theistic understanding in which evolution was understood as the mechanism through which a creator operates. Thus, Meredith, unlike Tyler and Meredith, continually used what she understood as the scientific explanation of evolutionary change as her own personal explanation.

Unlike Tyler, Meredith's early interviews were nearly devoid of religious reference. This omission may reflect Meredith's early separation of science and religion. Meredith's initial conceptual framework emphasized the nature of evolutionary changes and consisted of many alternative conceptions for the process of evolutionary change, much like Tyler's early conceptions. As the study progressed, many of Meredith's alternative conceptions were replaced with their scientific counterparts. Pragmatically, she became conversant with enough evolutionary theory to be at ease during our conversations. However, her conceptual framework stopped at this level of application. Evolutionary metatheories never formed a significant portion of Meredith's framework. At the close of the study, Meredith had a basic, scientific conceptual framework for evolutionary theory in which the nature and process of evolutionary changes were stressed. Meredith, like Brian, was notable in the lack of conflict these new constructions caused. Her case study is also notable in that Meredith believed in evolution long before she had a scientific framework for this topic. Like the students described by Lawson and Weser (1990), Meredith's early acceptance was based more on sociological considerations than the logical coherence of the theory. While the construction of individual conceptions followed a linear, logical pattern for Meredith, when the whole of the framework is taken into account, much of Meredith's conceptual change was initiated by extra-logical factors.
Conceptual Frameworks for Evolution

While each interview participant entered the study with differing conceptual frameworks, there were some commonalities in their conceptual frameworks. Conceptions reported in this category include only alternative conceptions about scientific topics. Nonscientific beliefs, "conceptions that cannot be accepted or rejected on the basis of scientific evidence," are not addressed in this section (Smith & Siegel, 1993, p. 599). Many alternative conceptions used by the four interview participants had been documented previously in the science education literature. These common alternative conceptions and an example of the literature which describes them can be found in Table 7. Other alternative conceptions were documented in this study but have not been previously described in the science education literature. These are discussed in Chapter 7.

Need, Anthropomorphism, and Teleology

Three of the alternative conceptions found in Table 7 warrant further discussion. Students' use of need as the origin of variation and their reliance on teleology and anthropomorphism for explanations of evolutionary events have been well described in the literature. It has been discussed that these three conceptions may be an artifact of verbal and written communication (Clough & Wood-Robinson, 1985b; Halldén, 1988; Jungwirth, 1975b). The data reported in this study only partially support this assertion. Meredith's final exam responses demonstrate that students can rely on the uncomplicated response of need as a means of expressing a far more complex conceptual framework for an evolutionary event. In contrast, as was seen in the early interviews with Tyler, high school students can also understand need to be the mechanism that is responsible for the production of variation and subsequent changes in a population. In Tyler's case, the use of need was not an artifact of communication, instead it was an accurate reflection of her conception for the origin of variation.
These findings support Brumby's (1984) assertion that students' "intuitive Lamarckism" is a real conception which must be addressed by science educators.

The situation is similar to students' use of anthropomorphism in their explanations of evolutionary events. As was made clear by Tyler's interviews and other students' in-class questions, many students are capable of understanding organisms to be able to complete physiological changes and subsequent evolutionary events through conscious means. This demonstrates that anthropomorphism is not used solely as a means to ease

Table 7
Alternative conceptions used by the interview participants and some of the literature which describes them

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>Reference</th>
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<tbody>
<tr>
<td><strong>Species Concept</strong></td>
<td>Bishop &amp; Anderson, 1990; Greene, 1990; Settlage, in press</td>
</tr>
<tr>
<td>Typological species concept</td>
<td></td>
</tr>
<tr>
<td><strong>Unit of evolutionary change</strong></td>
<td>Bishop &amp; Anderson, 1990; Demastes &amp; Good, 1993</td>
</tr>
<tr>
<td>All individuals in a population undergo an evolutionary change</td>
<td></td>
</tr>
<tr>
<td>A single individual in a population undergoes an evolutionary change</td>
<td></td>
</tr>
<tr>
<td><strong>Origin of variation</strong></td>
<td>Deadman &amp; Kelly, 1978; Demastes &amp; Good, 1993; Jimenéz, 1992</td>
</tr>
<tr>
<td>Need*</td>
<td></td>
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<tr>
<td>Conscious decision*</td>
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<tr>
<td>Use/disuse</td>
<td></td>
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<tr>
<td>Teleological explanations*</td>
<td></td>
</tr>
<tr>
<td>Origin of variation blended with natural selection</td>
<td></td>
</tr>
<tr>
<td><strong>Other categories</strong></td>
<td>Brumby, 1984; Lucas, 1971; Kargobo et al., 1980</td>
</tr>
<tr>
<td>No distinction between adaptations</td>
<td></td>
</tr>
<tr>
<td>Genetic dominance equated with phenotypic characters</td>
<td></td>
</tr>
<tr>
<td>Anthropomorphism*</td>
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</tbody>
</table>

*Note. Conceptions marked with an asterisk will be further discussed in the text.
communication or as a heuristic device as was suggested by several researchers (Halldén, 1988; Jungwirth, 1975b). Instead, like need, anthropomorphic responses can be an accurate reflection of a student's conceptions.

Unfortunately, these findings do not simplify the researcher's labors. As was seen in Meredith's and Stephanie's verbal explanations of their exam responses, need and anthropomorphism can also be used as a heuristic device as has been tentatively suggested in the literature. Given only written expressions of conceptions of need and anthropomorphism, it is very difficult to determine the conditions of the student's use of these conceptions. As has been suggested by White and Gunstone (1992), mode validity of research findings are of great importance in such questions and multiple means of data collection are necessary to ensure this validity.

Teleological responses are difficult to address given the data from this study. While Stephanie was teleological in her initial conceptions of patterns of evolutionary change, this conception became far less prominent in her later interviews. During this same time period, Stephanie was undergoing significant conceptual change regarding the process of evolutionary events. While generalizations become less meaningful when such limited data are available, these data do suggest that teleological expressions can be replaced by more mechanistic conceptions.

What is not answered by these data is the issue of the influence of the use of need, anthropomorphism, and teleology. Lakoff and Johnson (1980) suggest that the use of common metaphors and analogies serve to shape conceptions, instead of acting as simple expressions of conceptions. Do students use need, anthropomorphism, and teleology as a means of expressing their pre-existing conceptions? Or, does the early use of such responses act to shape and further embed these conceptions? This study cannot answer the question of the influence of these metaphors.
CHAPTER 7

CONCLUSIONS AND IMPLICATIONS

I learned several things from this research, such as the real importance of the mode validity of findings of educational research, the ways in which the tone and structure of interviews must change over time, and the insight students can have in their own reasoning and learning processes. However, the knowledge I most value concerns my understanding of the process of conceptual change.

At the outset, the conceptual change theory attracted my attention because it included an understandable and historically based mechanism to model learning. This model emphasized the importance of students' conceptual frameworks in the learning process. Because of this emphasis, interest in students' prior knowledge became a legitimate avenue of research. Something many science educators always felt was important now assumed a central role in learning theory.

As it was originally proposed, the conceptual change as described by Posner et al. (1982) has some very specific characteristics, some of which are absolute requirements of the theory and others which are implied by the theory's mechanism. Whether overtly or tacitly, these characteristics have shaped science educators' conceptions of science learning. But based on my research findings, my understanding of the process of conceptual change has undergone a series of meaningful changes.

In order to better frame my current description of the process of conceptual change in evolution, I will first illustrate my former interpretation of the conceptual change theory. As described by Posner et al. (1982), the conceptual change theory requires that four conditions must be met in order for a learner to undergo large scale accommodation of a pre-existing conceptual framework. These four conditions include:

1. The prior conception must be judged to be incapable of solving current anomalies (learner dissatisfaction),
2. The new conception must be found to be intelligible by the learner.

3. The new conception must be found to be plausible by the learner (that is, the new conception must solve all the problems the pre-existing conception could not answer), and

4. The new conception must be found to be fruitful (that is, the new conception must open other avenues for research).

Along with these four conditions for conceptual change, a learner's conceptual ecology is understood to control the change which can occur. As discussed previously in Chapter 2, this ecology is said to include the learner's epistemological commitments, metaphysical beliefs, the criteria a learner uses to control the recognition of anomalous data and knowledge taken from outside the field.

Based on this brief description, I understood the conceptual change described by Posner et al. (1982) to have several specific characteristics and/or limitations. These included:

1. The conceptual change theory was useful in describing the change of major, organizing conceptions. It was not meant to describe the change of small or minor conceptions.

2. Conceptual change was understood to be wholesale, so that the prior conception was completely discarded in favor of the new conception.

3. Conceptual change was a rational process in which evidence is logically analyzed and competing conceptions are compared on rational grounds.

   Based on this characteristic, I expected conceptual change to proceed in a linear, orderly fashion.

4. Stemming from the influence of the learner's conceptual ecology, belief was understood to influence the conceptual change which occurs.
Implicit in this description is that conceptual change, as described by Posner et al. (1982), is fundamentally a scientifically rational process in which conceptions are judged using logical evaluation of available evidence. In this description, the terms **scientific** and **rational** become important signifiers to the current conception of learning. For many, the term **scientific** implies the familiar image of wholesale disproof, objective and precise observations, and a simplicity and elegance of explanations derived through deductive logic. Using this understanding, a **scientific framework** would include a set of linear explanations which are not exclusive nor redundant. A learner using a scientific framework would search for the single most valid and widely applicable explanation for a natural phenomenon. The term **rational** also carries with it a host of implied meanings. **Rational** judgments are understood to be solely within the cognitive realm. Traditionally, rational judgments (and so conceptual change) are said to be conscious decisions which exclude the influence of affective or motivational concerns.

The data for this research conflict with the traditional interpretation of learning using the conceptual change theory, as I will outline in the following chapter. While I support limiting use of the term **conceptual change** to describe the change of major organizing conceptions, I now understand the process of conceptual change in evolution in much broader terms than those outlined by Posner et al. (1982). Ways in which my description differs from the initial theory include:

1. The conceptual change described in this study included the wholesale pathway predicted by Posner et al. (1982); however, two other pathways of conceptual change were also identified in my study. These patterns illustrate that the change of major conceptions is not always holistic.
2. Despite directed instruction, conceptual change is not always along a pathway leading toward the construction of a more scientific framework. Conceptual change must include any restructuring of a learner's conceptual
framework (as evidenced by the pre- and posttest data from the entire class).

3. The conceptual change experienced by the four participants was often driven by extra-logical factors (rational factors, but not within traditional notions of rationality). Thus, the patterns of conceptual change were neither completely linear nor orderly.

4. Data from this study suggest that the role of a learner’s conceptual ecology is far more important and intricate than suggested in the original conceptual change theory.

Based on these factors, I now understand conceptual change in evolution to include wholesale, fragmented, and dual constructions patterns which are controlled by both rational (both logical and extra-logical) and extra-rational components (motivational and affective concerns). The following chapter will further detail these and other conclusions and highlight the most salient aspects of this research.

Conclusions

Several conclusions can be drawn from the data and discussion included in the previous three chapters. The most important of these include: (a) alternative conceptions unique to this study, (b) further description of the process of conceptual change and suggested refinements of the theory, (c) factors influencing conceptual change, (d) a description of the degree of biological literacy of the four student participants, and (d) the question of student participation and its influence on conceptual change.

Conceptions Unique to This Study

While the majority of alternative conceptions documented in this study have been described in previous science education research, a number are new or were documented previously in a superficial manner. These new conceptions include:
Conceptions of species
1. Hybridization between animal species is a natural source of variation,
2. The term species is a completely artificial category,
3. The species construct is dependent on several criteria (amalgam species concept),*

Conceptions of evolutionary process
4. All mutations are beneficial,
5. Collage conception of fitness,*
6. Evolution is an incremental change in the quality of a trait caused by mutation within the entire population,*

Other related conceptions
7. The theory of evolution should account for the origin of the earth, initial production of life and subsequent changes in natural populations,
8. Humans are not primates nor animals, and
9. Evolutionary events are predictable.

Of these nine conceptions, the three designated by an asterisk are particularly meaningful. The three conceptions indicate that learners often blend their pre-existing alternative conceptions with scientific conceptions in an effort to construct useful explanations for natural phenomena. This new, broad conception is then applied and further modified. This fragmented process of blending and subsequently modifying conceptions conflicts with the wholesale conceptual change described by Posner et al. (1992).

The conflict between the conceptual change documented in these three instances and that described by the conceptual change theory serves to reinforce the intended scope of the conceptual change theory. As was suggested in the original paper, the conceptual change theory should be applied to only major, organizing conceptions which is not the case in the three (*) conceptions discussed here (Posner et
al., 1982). However, other science education researchers have strained to apply conceptual change theory to almost all instances of learning and have thus ignored the intended constraints. While this over-application mirrors the growth of almost all scientific theories (Duschl, 1990), these data indicate that researchers must remember the intended scope of this theory.

Conceptual Change

The data can be used to address four broad areas describing the process of conceptual change for biological evolution. These include:

1. The impact of the learner's conceptual ecology on the process of conceptual change.
2. The importance of threshold questions on the process of conceptual change.
3. The patterns of conceptual change.
4. Actions of competing conceptions.

Conceptual Ecology and Conceptual Change

Tyler, Meredith, Stephanie, and Brian were not only participants in this study; they were students in a specific classroom, situated in a unique educational setting and influenced by a myriad of factors. An important aspect of the understanding that I have constructed in this study revolves around my interpretation of their school and classroom culture. To understand how the conceptual frameworks of the participants changed is, in part, to understand the influence of culture on this process.

At the outset of this section, it must be noted that each of the four interview participants had one important characteristic in common--each had a very favorable attitude toward almost all academic work. In this regard, these participants were not radically different from their classmates. An important feature of the classroom culture was a positive orientation toward academic knowledge and academic achievement. Dreyfus, Jungwirth, and Eliovitch (1990) describe this level of engagement as one of the most important considerations for conceptual change. Strike
and Posner (1992), too, have recently described the potential influence of learners' motives and goals on the process of conceptual change. The results of a conceptual change study by Lee and Anderson (1993) demonstrates the interactions of students' motivational and affective orientations and their knowledge and achievement.

Unfortunately, a positive orientation to classroom science is not commonly found in our nation's students. The influence of this unusual characteristic may be one of the most fundamental factors controlling the conceptual change documented in this study; however, no comparison is possible as it is a characteristic that each interview participant shared.

Features of the participants' conceptual ecologies found to play important roles in the conceptual change which occurred included the learner's orientation toward science, other sources of academic knowledge, and religion. As was particularly stressed in the multidisciplinary realist's case study (Stephanie), a learner's epistemology and goals for the learning process can also play a major role in controlling the conceptual change that can occur.

Overall, the data support Posner et al.'s (1982) assertion of the importance of the learner's conceptual ecology on the process of conceptual change. However, the most significant finding within this category was the documentation of significant conceptual change in the absence of a corresponding change in belief. As was seen in Stephanie's case study, a learner who personally rejects the truthfulness of evolution can experience considerable change toward a scientific conceptual framework for this topic.

The documentation of a disjunction between academic understanding and personal belief conflicts with the common perception of some evolution educators (Nelson, 1986). However, these data support the quantitative findings of Bishop and Anderson (1990) and Demastes et al. (in press) who failed to document a strong
association of students' beliefs and their ability to apply a scientific conception for an issue of evolutionary theory.

It could be argued that Stephanie was able to construct a largely scientific conceptual framework for the process of evolution despite her disbelief because of her multidisciplinary epistemological approach. Unlike many students who use a creationist view, Stephanie was able to appreciate the value of evolutionary theory regardless of her belief in the topic. While she did not regard this theory as true, she did consider it to be worthy of academic consideration. This may have placed Stephanie in a unique position allowing learning to occur under typically adverse circumstances.

Stephanie's case study becomes more informative as it is compared to Tyler's. Tyler was not as adamant in her rejection of evolutionary theory as Stephanie, yet her discomfort and confusion were often obvious. It may not be coincidental that the student (Tyler) who had the most difficulty in constructing scientific conceptions for evolutionary mechanisms was also the student involved in the greatest amount of personal turmoil regarding this topic. The resolution of the teacher's and learner's anxieties in regard to evolutionary theory has been addressed in a systematic research program (Scharmann & Harris, 1992). The comparison of Stephanie and Tyler suggests that the most influential factor inhibiting scientific conceptual change is not belief, but the learner's feelings of disturbance and conflict as learning occurs.

In contrast to Stephanie's case study, Meredith accepted evolutionary theory long before she had a scientific conception for the process of this theory. This is not an unusual situation. In a survey reported by Lord and Marino (1992), while 75% of the college students polled reported that they believed evolution, most failed to understand the process. Like Tyler and the students in Lawson and Weser (1990), Meredith's acceptance was based on her perception of the academic authority of this theory and
the persons teaching this theory instead of the intrinsic intelligibility, plausibility, or fruitfulness of the theory itself.

It could also be argued that the learning documented in Stephanie's case study is not a typical example of conceptual change. Using the criteria of Posner et al. (1982), because she did not reject her existing conceptual framework for this topic, Stephanie could be said to have undergone only the initial process of finding the theory intelligible and plausible. However, portions of Stephanie's larger conceptual framework did undergo a definite change away from her initial conceptions.

A learner's conceptual ecology also includes the student's approach to scientific topics. A comparison the authority seeker's (Tyler) case studies to the other cases of the other three participants reveals that the learner's overall approach to understanding natural phenomena (her/his world view) can play an important role in aiding or hindering the construction of a scientific conceptual framework. Brian, Meredith, and Stephanie, were capable of a very mechanistic, naturalistic approach to scientific topics. Each of these three made considerable gains toward the construction of a scientific conceptual framework for evolution. However, Tyler who used a more aesthetic approach to understanding natural phenomena retained the use of many of her prior alternative conceptions for much of evolutionary theory at the end of the study (Coburn, 1993). Unfortunately, Tyler's additional reliance on academic authorities and her personal turmoil complicate this analysis.

When the conceptual frameworks and conceptual change of the participants' are analyzed, areas of difficulties emerge which reflect the particular cultural context of these learners. These sites of struggle may reflect basic assumptions of western culture which must be overcome in order to construct a scientific conceptual framework for evolution. These three sites include (a) humans as separate from nature, (b) the Aristotelian notion of a ladder of life, and (c) the inherent predictability of physical mechanisms. These issues proved to be very important features of the learner's
conceptual ecologies and took the form of barriers to be overcome in the conceptual change of Meredith, Tyler, and to a lesser degree Stephanie.

**Students' Threshold Questions about Evolutionary Theory**

The original description of conceptual change theory outlined the importance of a theory's (a) intelligibility, (b) plausibility, and (c) fruitfulness. Related to this, the data from this study support the prominent role of particular issues, which can be called **threshold questions**, in the process of conceptual change in evolution. The term **threshold questions** was selected because it describes the actions of such information. If the learner obtained the correct answer to such a question, she/he could proceed with the construction and acceptance of the new conception. If the learner could not obtain this information, further learning was blocked.

This sequence of events is demonstrated as Stephanie's case is followed. When she entered the class, she had the alternative conception of "interbreeding for dominance" as being the only source of new variation. However, this explanation was not often applied and it was clear this conception was not central to her conception of the process of evolutionary change.

(When asked about the origin of variation)

**ST:** I have a hard time forming opinions about this. I really don't think we can form something just because we need it.

[D 15]

After she learned that mutations are the source of variation, an entire sequence of changes were made possible for her understanding of the process of evolutionary change. This conception made the explanation of the process of evolutionary change plausible for Stephanie. The subsequent conceptual changes can be found in the description of her mid-year conceptions.

Other threshold questions documented in this study include:
Threshold Questions of Intelligibility:
1. How could two different species stem from one original?
2. Why haven't all species evolved into a similar, better organism? (Or, why does evolution stop?)
3. How does evolution explain the creation of the earth?

Threshold Questions of Plausibility:
1. Have humans evolved?
2. What is the origin of variation in a population?

Threshold Questions of Fruitfulness:
1. Can evolution explain similarities and differences between organisms?
2. Can evolution be used to explained structural peculiarities between organisms?

As these questions are reviewed, it should be remembered that the actions of such knowledge vary from learner to learner. It is also important to note that these threshold questions do not have to be answered in a logical manner. As emphasized by Tyler's case study, the most important question which allowed evolution to become plausible was the issue of human evolution. Having answered that, she never raised questions concerning the patterns or modes of speciation.

Evidence Needed for Conceptual Change

Closely related to the idea of threshold questions is the evidence required by learners for conceptual change. As recalled in the discussion of conceptual change teaching provided by Duschl and Gitomer (1991, p. 847), "what counts [as evidence] is affected by what knowledge we choose to embrace." The participants in this study did not always select evidence based only on rational, logical reasons. Instead, idiosyncratic, measures were often used. An example of this was seen in Stephanie's case study. She understood and constructed a conception of small scale evolutionary changes because of her interests in anthropology. For Stephanie, the process of small
scale evolutionary events needed to become plausible to justify her affective concerns and her extensive prior knowledge in anthropology. A similar example was seen in Tyler, who understood the world to have a very long history only because of her perception of the existence of dinosaurs. For Tyler, the world was old, not because of an array of supporting evidence, but because it had to be old in order for dinosaurs to have existed.

The understanding that all conceptual change in a learner is not logically driven is not in conflict with the description of conceptual change in science as provided by Lakatos (1970), Toulmin (1972), and Kuhn (1970). Toulmin (1972) describes the rationality driving theoretical change in science as often being outside the boundaries of formal logic and instead being a systematic analysis of the practical considerations of the function and adaptation of the new theory. It should not be surprising that much of the conceptual change documented in this study was not driven by logical considerations but was still based on a rational evaluation of the function and implications of the new conception.

Patterns of Conceptual Change

Change in one conception

As seen many times in the data of this study, the initial stages of the change of a single conception were characterized by the student's use of a new term within a previously constructed explanation. Often, the initial use was not accompanied by a full, scientific understanding, but instead an almost rote mimic of an earlier use. This process was seen in Meredith's initial use of mutation in her explanation of the process of evolutionary change. She first mentioned the term after reading it on a pretest. It was clear that Meredith did not understand what this term signified, but instead used it to fill a gap in her previous understanding of evolutionary change. In later interviews Meredith began to apply this term in more of her explanations that gradually narrowed the scope of mutation's actions as she more closely defined the term. It was not until
the mid-year and year-end interview periods that Meredith constructed a scientific conception of the process of mutations and its actions. However, this conception came long after her initial use of this conception in response to her own dissatisfaction.

Another trend seen in a single instance of conceptual change was the change in the students' use of a conception. As was seen in all four interview participants, students' initial applications of a conception were often tentative and took the form of rapid but unsure responses to interview questions. Later applications of the new conception were made with more assurance as the students began to link the new conception with other aspects of their knowledge. Links between conceptions were reflected in students' concept maps (as the new conceptions were placed higher in the map's hierarchy) and in their frequent use of such responses in interview responses. Tentative beginnings characterized conceptions constructed in response to learner dissatisfaction with current conceptions.

Change in related conceptions

Often the change of one conception allowed a sequence of conceptual changes to occur. An example of this was demonstrated in Stephanie's and Meredith's use of need as the origin of variation. While this alternative conception remained in place, other associated conceptions also remained in an alternative state. But a change in the controlling conception allowed for a cascade of associated changes. A tentative sequence of this cascade was as follows:

1. Need was replaced by mutation as the origin of variation.

2. The conception of patterns of evolution as tied to the environment was replaced by a conception of evolutionary patterns having a more random component.

3. The conception of an inextricable action of natural selection and production of variation was replaced with a conception of the separate actions of these two processes.
4. The conception of the unit of evolutionary change as being the entire population was replaced by a percentage of the entire population.

It is difficult to determine the exact sequence of each of these conceptual changes because the cascade always occurred over a short time span. More work is required to tease out the actual controlling conception. However, previous work indicates need as the controlling conception of this cascade (Demastes & Good, 1993). Aside from identification of the controlling conception, documentation of this series of changes is insightful. Millar (1989) suggests that a model of knowledge fragments instead of conceptual frameworks may be a more fruitful model for students' understandings. The data collected in this study lend partial support to this model. Students' conceptions of the many facets under a broad theoretical base can change with little alterations of the other portions of the framework. For example, Stephanie's knowledge of the mechanism of evolution changed while her historical knowledge was retained intact. However, some of the data conflict with Millar's model. The conceptions which describe related biological phenomena often change in a very interconnected fashion, as is described by the cascade of changes. Based on this study, Millar's model of knowledge fragments is only applicable within specific instances in evolution education.

Conceptual change versus change in formal knowledge statements

Another characteristic of most instances of conceptual change was that the actual conceptions applied by the learner would undergo an alteration, but their overarching, descriptive explanation would be retained unchanged. Stephanie's case study best demonstrates this characteristic. At the outset of the study, Stephanie recognized "subtle changes within a group" of organisms as the only plausible description of evolutionary change. Using this conception, she rejected all large scale examples of speciation. However, during the latter stages of the study, Stephanie accepted and applied evolutionary theory to account for changes "within" a group
encompassing dinosaurs and birds and reptiles. She retained the use of the formal
definition of evolutionary change, but the meaning she attributed to this statement
varied.

Documentation of such subtle conceptual change calls into question the
wholesale change described by Posner et al. (1982). Stephanie’s understanding of the
scope of evolutionary changes is a large, organizing conception. Yet, in the instances
described above, Stephanie was not consciously selecting one conception over another
based on issues of intelligibility, plausibility, and fruitfulness. Instead, her previous
conception was undergoing a series of subtle changes in order to envelop the new
information she was learning. Such piecemeal and gradual conceptual change is
similar to the pattern described by Nussbaum (1989, p. 538):

[Conceptual change] forms a pattern in which the student maintains substantial
elements of the old conception while gradually incorporating individual
elements from the new ones.

Gradual conceptual change has also been documented by Metz (1991) in her study of
change in students’ physics knowledge. In this study she described both wholesale
conceptual change and an incremental pattern. Within the incremental pattern,
students’ pre-existing conceptions are transformed and serve as the basis for new
conceptions.

Recognition of conceptual change

Within the conceptual change theory, a learner compares two competing
conceptions and elects to use one conception based upon the criteria described
previously. If such comparison is common, a researcher might expect to see signs of a
learner’s recognition of the process of conceptual change. This prediction is supported
by many of the data of this study. Particularly true in Stephanie’s and Meredith’s case
studies, they recognized and could propose reasons for the conceptual change that
occurred during this study.
The trend of recognition of conceptual change did not hold true for all conceptual change, however. As demonstrated by Stephanie's changing conception of evolution as "subtle changes within a group," learners often are not consciously aware of the conceptual changes which occur. Just as a recognition of this process supports Posner et al.'s (1982) description, the lack of recognition calls into question the limits of this theory. As was suggested in the previous section, change of an organizing conception is not always through the overt process of comparison and rejection. Instead, as has been recently suggested by Strike and Posner (1992), conceptual change is often a more fragmented, extra-logical process that is guided by the learner's prior knowledge and affective considerations of this knowledge.

**Actions of Competing Conceptions**

During two instances in the study, students failed to recognize their application of two logically incompatible conceptions. This was seen in Meredith's and Tyler's recognition of the random aspect of mutation combined with their application of only beneficial mutations. After the initial documentation of this event, I took measures to ensure that these two students were applying these conceptions and not simply stating a rote answer. Once this was established, I questioned them as to this inconsistency. Neither participant was able to recognize the incompatibility of these responses. Additionally, it is important to note that each one of the conflicting responses was elicited by a different interview question. Inconsistent knowledge frameworks are well known in science education literature (Carey, 1985; Clough & Driver, 1986; Gilbert, Watts, & Osborne, 1982), and have been previously described for students' conceptions of evolution (Lawson & Thompson, 1988). The data from this study and the literature suggest that occasionally conceptual change can include the construction of a second equivalent but competing conception.

Lawson and Thompson (1988) suggest that students fail to recognize the inconsistency of the competing conceptions and fail to experience wholesale
conceptual change in these instances because they do not have the required reasoning skills. Other authors have noted these dual constructions are elicited through different activities (Carey, 1985; Clough & Driver, 1986). In any case, based on these data, the dual construction and application is a common event in the process of conceptual change. Holland et al. (1986) use the default hierarchy model of cognition to explain learners' selection of one conception to use from a dual construction. However, the extra-logical pattern of concept selection used by Meredith, Tyler, and Stephanie makes the use of this computer metaphor problematic.

**Summary of Patterns of Conceptual Change**

Currently, two metaphors for conceptual change are commonly accepted. One describes that a learner's conception can undergo subtle changes in the form of assimilation and the second describes the process of whole sale accommodation as conflicting information is encountered. The conceptual change theory of Posner et al. (1982) was designed to address only instances of accommodation for major, organizing conceptions. The data from this study conflict with this narrow description. These data describe three patterns of change for major conceptions: (a) wholesale, as suggested by Posner et al. (1982), (b) fragmented and gradual, as suggested by Nussbaum (1989) and Metz (1991), and (c) dual, as the discussion shown above illustrates.

**Factors Influencing Conceptual Change**

**A Comparison**

When the conceptual change of the interview participants is compared with that experienced by the entire class, a considerable discrepancy emerges. Not surprisingly, a comparison of the pre- and posttest responses of the participants and their classmates reveals that the participants learned a great deal more evolutionary theory than their classmates. This difference could be attributed to several factors stemming from the interview process. The interview participants were involved in a conversation
regarding evolutionary theory on a weekly basis. The sheer frequency of our
discussions could have been responsible for the greater degree of learning found in the
interview participants. Also due to these conversations, evolution gained an
importance for the participants that was lacking in the larger class. As Meredith explained:

M: Like whenever we've talked about it [evolution] in class I probably paid
more attention than you know ahm, I've paid careful attention because you
know, it's something that we're talking about each week. (A 313)

Dole and Niederhauser (1990, p. 309) suggest that a learner's "personal need to
know" plays a very large role in initiating and guiding the process of conceptual
change. They suggest that the interest an issue holds for a student increases the
possibility of conceptual change. This view is supported by West and Pines (1983)
who argue that affective considerations of learning should not be excluded in the
research of conceptual change. Certainly, the four interview participants learned to
care about the theory of evolution because "it's something that we're talking about each
week," and that interest enhanced the learning that occurred.

Additionally, the interview process clearly demonstrated the gaps in a
participant's explanation of an evolutionary event. Such explicit knowledge allowed
for learner dissatisfaction and caused the participant to search for other more suitable
answers both in class and in our later interviews. Related to the issue of
dissatisfaction, the structured interview activities provided a means through which the
participants could explore the implications of their current conceptions. Jimenéz
(1992) demonstrates that such explanation is an essential aspect of conceptual change.
Again, this opportunity for dissatisfaction was not afforded the larger class of students.
Based on the comparison of data from the whole class with the interview participants,
it is evident that the interviews served as a learning medium.

The other source of discrepancy between the conceptual change documented in
the interview participants and the larger class lies in the means of data collection used
for whole class. Like previous studies, whole class conceptual change was studied using written data for pre- and posttesting. As was demonstrated in the posttest data in both Meredith's and Tyler's case studies, written explanations often do not adequately reflect the learner's true conceptual framework. It is possible that the conceptions used by the whole class were different than those expressed in their pre- and posttest responses. To clearly isolate differences between interview participants and the whole class, another means of data collection must be used.

**Classroom Activities Affecting Conceptual Change**

Many of the classroom activities employed by Ms. Hurston were instrumental in triggering the process of conceptual change. The most influential activities/units can be found in Table 8.

<table>
<thead>
<tr>
<th>Activity/Unit</th>
<th>Targeted Conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal behavior</td>
<td>Human and primate relationships</td>
</tr>
<tr>
<td>Anthropology</td>
<td>Humans and primate relationships</td>
</tr>
<tr>
<td>Dinosaurs</td>
<td>Applications of evolution</td>
</tr>
<tr>
<td>Science 82 reading</td>
<td>Scope and process of evolution</td>
</tr>
<tr>
<td>Exams questions</td>
<td>Extinction/human and primate relationships</td>
</tr>
</tbody>
</table>

Of the activities or instructional units listed in Table 8, it is surprising that the activity with the greatest amount of influence on the interview participants was the **Science 82 reading**. Entitled, "Evolution since Darwin" (Rensberger, 1982), this brief article addressed basic tenants with Darwin's theory of evolution, provided a historical overview of the theory, discussed current controversies, and described various theories of the scientists working within this framework. After reading the article for homework, each of the interview participants applied the concepts described in the
article during research sessions. Some of these concepts remained embedded in the participants' frameworks of evolution throughout the remainder of the course. Perhaps such an application would have occurred after a simple reading, but Hurston lead a vigorous discussion of the article during a later class session. It should also be noted that the participants were aware of the deficiencies in their explanation before reading the article. This recognition may have been the factor responsible for making the article a particularly powerful teaching tool.

Classroom Discussions and Conceptual Change

Implicit in Hurston's teaching habits and my own observations and descriptions of her classroom is our expectation that overt participation in discussions encourage students' conceptual change. This view of conceptual change is shared by other researchers in the field who stress the importance of discussion in the assessment of rival conceptions (Duschl & Gitomer, 1991). However, it is not only within the conceptual change theory that discussions are valued. The current constructivist view of learning relies heavily on Vygotsky's work in his emphasis of the importance of social interaction in a learner's construction of knowledge (Rogoff, 1990). Similar to Hurston and to my own interpretation, it is clear from many of the current studies that Vygotsky's social interaction has been interpreted as an active, vocal participation in conversations. The AAUW (1992) quantified the relative amount of time boys and girls, as well as majority and minority students, overtly participated in classroom discussions. Researchers concerned with male "domination" of science classrooms often quantify the amount of time a student talks in class or overtly participates in classroom demonstrations (Tobin & Garnett, 1987).

During my classroom observations, I was concerned that so few of the girls in Hurston's class chose to participate in the frequent discussion Hurston often relied on for teaching. Given my interpretation of the conceptual change theory, I understood overt participation to be an essential component of a learner's consideration and
eventual change of conceptions. Based on my assumption, I predicted that the female members of the classroom and other silent class participants would experience less conceptual change than those members who took part in classroom discussions. Like other researchers, I expected the silent learner to experience less conceptual change.

Unfortunately, based on the methods of my study, the influence of gender and participation on conceptual change could not be investigated. As explained in the preceding section, my study constituted an intervention in which weekly discussions with my more silent participants, (Meredith, Tyler, and Stephanie), provided these learners an opportunity to assess their conceptions. Other girls in the study did not have this avenue, and using current interpretations of the conceptual change theory we might expect them to have experienced a lesser degree of conceptual change than the boys in the classroom.

However, the prediction that less vocal participation would result in lower degrees of conceptual change is not as indisputable as it first appears. In our conversations, Stephanie explained that she often learned through listen to class discussions. Her observations are supported by Belenky, Clinchy, Goldberger, and Tarule (1986) who suggest that often women do not participate in group discussions because they learn best through observation and listening. These individuals learn through "hearing themselves think" (p. 85). This seemingly less participatory learning style allows women to compare their own thoughts with those being expressed in the classroom. While the description of women's modes of communication and learning described by Belenky et al. (1986) are far too lengthy to describe here, Stephanie's comments made throughout the study lend support to this description of active, yet silent learning. Stephanie frequently commented that she "was learning" during a discussion in which she made no comment.

As educators, we should not make the mistake of assuming that all students learn science the same way. Perhaps science educators should be less concerned with
"enlisting" the overt participation of the girls and more concerned with ensuring that such discussions become a valued and meaningful aspect of teaching and learning.

Biological Literacy

Regardless of the effects of the research process and instructional activities listed in Table 8, the influence of Hurston's integrated approach to teaching evolution cannot be discounted. As reflected in Appendix F, Hurston touched on the evolutionary concepts throughout the biology II course. Evolutionary theory grounded her teaching, and this foundation is reflected in her selection of instructional units and in her examinations. While most students in her class as a whole did not demonstrate significant conceptual change regarding the process of evolution, they made noteworthy gains in learning to apply this theory to biological data. The research of Cummins et al. (in press) also suggests that Hurston's teaching was particularly successful in developing students' abilities and tendencies toward application of this theory. While Hurston's style of questioning and discussion does not closely adhere to the conceptual change teaching environment described by Smith et al. (1993), these very characteristics may be largely responsibility for her success in eliciting student participation in the learning process, a participation which allowed for student driven development and application of theories. Students in Hurston's class were encouraged to weave together the various aspects of evolutionary theory into a coherent mental model, which could then be used to understand the ultimate actions of evolution (Anderson, 1984). In this manner her teaching does resemble the conceptual change teaching environment described by Duschl and Gitomer (1991). Additionally, these activities could be described has moving students toward a multidimensional degree of biological literacy because of Hurston's emphasis of the application of diverse knowledge to real-world problem solving.

It is perplexing that most students in the class developed an ability to apply a concept of evolution without developing a fundamentally scientific understanding of
the process. Students in Hurston's class could use the theory to explain biological situations, but they did not understand the process through which evolution operates. This situation was not reflected in my interview participants. These students experienced an increasingly scientific understanding of the mechanism of evolution combined with a changing conceptual ecologies. These changes were accompanied by more acute expectations that such a theory could and would explain biological data.

Implications

The findings of this study have several implications, both for science teaching and other science education research. These include (a) students' abilities to learn aspects of evolutionary theory, (b) patterns of and influences on the processes of conceptual change in evolution, (c) unanswered questions concerning students' use of teleology and anthropomorphism in the content area of evolution, and (d) methodological implications of the study's reflexivity.

Students' Abilities to Learn Evolutionary Theory

The first implication of the research is illuminated by a comparison of the students' knowledge upon entering the course and their knowledge as the course ended. In their groundbreaking study linking conceptual change theory with the learning of evolution, Bishop and Anderson (1990) noted that learning this topic is a very difficult process. The findings of the present study support this assertion. As Wandersee et al. (1993) suggest, a change in a learner's conceptual framework becomes even more difficult when that framework has many links to other aspects of a learner's prior knowledge, that is, their alternative conceptions. This difficulty is demonstrated in the whole class performance on pre- and posttesting. Despite the concentrated, mechanistic, and integrated instruction of evolution the juniors were exposed to in a previous course, many of these same students retained use of prominent alternative conceptions for the mechanism of evolutionary change.
The intrinsic difficulty of learning in evolution was also demonstrated by the modest-to-negative changes seen in students' pre- and posttest performance. However, echoing the findings of Settlage (in press) and Jiménez (1992), this study demonstrates that high school students can be successful in the construction of scientific conceptions for facets of evolutionary theory. As was seen in two students in this study, high school students can achieve multidimensional biological literacy for this biological concept. Clearly, the content of evolutionary theory is not beyond students' reasoning abilities. However, as was seen with the interview participants, the instructional means used to nurture such conceptual change must be intensive, engaging, and of long duration.

Patterns of and Influences on Conceptual Change

Patterns for Minor Conceptions

This research also has theoretical implications for the conceptual change theory as it is applied to science learning. As was demonstrated by the participants' changing conceptions regarding subtle aspects of evolutionary theory (i.e., species concept, fitness, unit of evolutionary change), conceptual restructuring of minor conceptions does not follow the wholesale pattern described by the conceptual change theory of Posner et al. (1982). Instead, these examples serve to confirm and emphasize the limitations of this theory as a description of the restructuring of major, organizing conceptions.

Patterns for Major Conceptions

Even within major, organizing conceptions, the findings of this research suggest a need to change the current model of conceptual restructuring described by the conceptual change theory. While the pattern described by the Posner et al. (1982) model was identified in the conceptions of the interview participants, other patterns of conceptual change were also seen. The patterns of conceptual change for major, organizing conceptions of evolutionary theory identified in this study include (a)
wholesale, as suggested by Posner et al. (1982), (b) fragmented and gradual, as suggested by Nussbaum (1989) and Metz (1991), and (c) dual, as competing conceptions are constructed and use of the prior conception is partially retained. The presence of these three patterns illustrate a need to broaden the description of the actual patterns of conceptual change and to narrow the applications of the present conceptual change theory to describe only instances of holistic conceptual change.

Further research is needed to investigate the patterns of conceptual restructuring within other theoretical frameworks both in biology and other science disciplines. Are the three patterns described in this research exhaustive of all conceptual restructuring of major, organizing conceptions? Are the patterns of change identical for both minor and major conceptions?

The patterns of conceptual change have implications for the classroom teacher. Because a student's conceptual framework can undergo the construction of dual conception, the role of the science teacher can be understood to take two paths. A teacher may need to teach the reasoning strategies necessary to select the scientifically appropriate conception, or the teacher's role may be to establish classroom activities that consistently and frequently use cues (classroom situations) that are successful in eliciting the scientific conception. Further work is required to further investigate the presence of the dual constructions and their classroom implications.

Patterns of Related Conceptions

The data from this study reflect the complexity needed for a useful description of conceptual change within a conceptual framework as broad as biological evolution. The conceptual change described in this study can simultaneously be referred to as interwoven and independent. As suggested by Millar (1989), in some cases, conceptual change can occur in a very independent fashion, with change in one conception having no effect on another conception within the same framework. However, for related conceptions, change was seen to occur in a cascade, with one
conception having direct implications for another as suggested by Nussbaum (1989).
The first of these two possibilities is liberating for the classroom teacher. In this case, teaching does not need to be tightly orchestrated or sequential. However, in the latter case, teaching should follow a planned sequence, allowing for a built-in pattern of related, gradual change. Further work is required to identify both related and independent conceptions in order to devise the most appropriate means of instruction.

**Conceptual Ecology**

Perhaps the most important theoretical finding of this work is that the actions and structure of a learner’s conceptual ecology vary with each individual. Strike and Posner (1992) describe the influence of conceptual ecologies as *interactionist*, a term which signifies the complex, fluid relationship between ecologies and conceptual change.

This interactive nature makes predictions of a learner’s potential to construct a scientific framework in this area difficult. For some learners, her/his epistemological approach to science may be the strongest controlling factor. Recently, Linn, Songer, and Lewis (1991) have discussed the growing recognition science educators have for the influence of a learner’s epistemology of science on their ability to learn science. For others, epistemology may play a secondary role to the personal emotions a learner has invested in the topic. As suggested by Lee and Anderson (1993), research into conceptual change should examine not only cognitive factors; instead, conceptual change research must begin to examine the influence of a learner’s motivational and affective orientations in science learning. Also seen seen in this study, a learner’s world view may play the pivotal role in controlling conceptual change. Several instances in this study demonstrate the limitations of the use of logical evaluation of conceptions described by the conceptual change theory. Instead, conceptual change was frequently less rational than the current model suggests, with the learner’s selection of a conception directed by extra-logical, affective considerations.
This study also demonstrates that it is ill-advised to design teaching strategies solely on the basis of a learner's self-professed belief in evolutionary theory. As was seen, belief does not signify or ensure understanding and, alternatively, disbelief does not preclude or prevent understanding. Instead, many other aspects of a learner's conceptual ecology must also be addressed.

The question of belief introduces an important issue. Should science educators seek to change basic belief structures? Or should we seek to make academic conceptions intelligible and plausible to the learners in such complex conceptual area as evolution? On this point I agree with the arguments of Smith and Siegel (1993) who side with the latter approach and explain that science teachers should also prepare students to critically examine biological evidence. The fate of conflicting belief structures should then be left to the learners.

Teleology and Anthropomorphism

Of all the research questions proposed at the outset of the study, students' use of anthropomorphism and teleology remains the least well understood question at the close of the study. The data demonstrate that students' use of need may be a controlling factor in a cascade of changes regarding the mechanism of evolutionary change. However, the means through which teleology and anthropomorphism influence the constructions of conceptions remains unclear. The broad scope of this study precluded an exhaustive treatment of this topic. Further detailed research is required to illuminate the questions of the actions of the teleology and anthropomorphism.

Methodological Implications of Reflexivity

In the third chapter, I discussed the implications of researcher-participant reflexivity in this study. Certainly, my voice and that of the participants played a role in shaping the research findings as well as the methods through which the data were collected. The actions of such reflexivity have been well documented in previous
qualitative studies (Munro, 1991; Roman, 1989; Stacy, 1988). However, the actions of this relationship become even more marked as the conceptual change of the research participants is compared to that of the students in the whole class. The four student participants were far more successful in constructing a scientific conceptual framework for evolution than those students enrolled in the course but not participating in the interviews. This discrepancy suggests that the interviews themselves became inadvertent but effective teaching instruments. This is a case in which more careful study formed a treatment of sorts. Thus, my study is not a description of how a typical high school student constructs a framework for evolution as much as it is a description of how a research participant situated an ideal learning situation constructs a framework. As conceptual change research moves toward the detailed and intensive study of individual learners, the effects of such research must be recognized. Additionally, later studies should move on from investigations of ideal conditions to describe the conceptual change which characterizes more typical classroom situations.
REFERENCES


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APPENDIX A

STUDENT BACKGROUND AND BIOLOGICAL LITERACY QUESTIONNAIRE

Student Survey
This survey is to help me become familiar with the students in the class. Feel free to ask questions and to use extra space to provide answers.

Name____________________________Age_________Grade____

1. Where were you born? How long have you lived in Baton Rouge?
2. How long have you attended this school?
3. What are your plans about your career after graduation?
4. Why did you enroll in this biology II class?
5. Do you watch science-related TV programs at home? (Shows like Nature, the Discovery Channel, National Geographic.) If so, how many hours per week?
6. Do you read about any science related topics outside of school? If so, please name any of the titles.
7. Do you read books or watch programs that are based on science fiction? If so, please name some of your favorite titles.
8. What has been your favorite subject in school? Please explain why its your favorite.
9. What are your hobbies outside of school?
10. Does any of your family work in science-related fields? If yes, please explain what they do.
11. Describe what you think a biologist does at work.

3 Note. This is not the actual form, but this version includes all the questions from the original survey.
APPENDIX B
SAMPLES OF THE OPEN-ENDED INTERVIEW QUESTIONS

B-1: Student Participants

Interview 1--School: Personal Information: Teaching
1. Tell me about this school.
2. How long have you been here?
3. Where did you go to school before?
4. How do you like it here?
5. What do your folks do?
6. Why did you come to school here?
7. How do you get into school here?
8. What other extra-curricular activities do you do?
9. Where do you think you'd like to go to college?
10. How did you pick those?
11. What do you want to do at those schools?
12. What do you think influenced that decision?
13. Okay, so talk me through a typical day.
14. Which class is your favorite?
15. What's your idea of a good teacher?
16. What do you think your responsibilities at school are?
17. What do you think is the function of high school?

Interview 2--Evolution: Mutation: Science/Biology
1. What do you think evolutionary theory is talking about?
2. Who taught you that?
3. So, what do you think evolution is? When we say something evolved, what does that mean?
4. Does that happen on an individual level or what? Like what evolved?
5. So individuals can't evolve?
6. Okay, do you know what makes evolution work?
7. Could you tell me what a science is?
8. How does biology differ from English?
9. Why did you take this biology class?
10. So what is biology about?

Interview 3--Animal Behavior: Pseudoscience
1. Did you like that unit on animal behavior?
2. Did you learn anything that you didn't know beforehand?
3. Do you think you view primates differently now than you did before you started the unit?
4. So, what do you think about the LockNess monster?
5. What do you think about Big Foot?

6. You don't think that's true either? Why?
7. So, what would it take for you to believe it?
8. So is that, is that how you equate truth, if it's a scientific thing?

Interview 4--World View
1. Science and religion, do you think of them as antagonistic, or ah, do you see them as one helping to explain the other?
2. When you think about how the world works, what are your ideas?

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3. Do things happen because there is a plan, or do things just happen?
4. So for you think things will always turn out. Well, do you extend that to other areas, like the natural world?
5. Let's say a species went extinct. Do you think that happened because of some scientific reason, or some other driving force?
6. So these scientific reasons, do they apply to people? Do they apply only the natural world?

**Interview 5—Scientific theories**
1. Could you tell me what a scientific theory is?
2. What's the difference between a theory and a hypothesis?
3. Are theories true?
4. What would they be called if they had been proven?
5. Can you prove things right? I mean, like right all the time?
6. Which one has more weight in science a fact or a theory?
7. So if we prove a theory right, like 20 times, 30 times, will it ever become a fact?
8. They way we think an atom is built, with nucleus and moving electrons, do you think that is a fact or a theory?
9. So what do you think the job of a scientist is?
10. Could you give me instances of rival theories?

**Interview 6—Human Taxonomy**
1. Do you think humans should be classified as apes?
2. Do you think that really?
3. So what can you tell me about primates? What makes something a primate?
4. So, do you think humans can be classified the same way animals can be classified? You know, we use that taxonomic system, kingdom, phylum, class, order, you know?
5. Can you say, or are you comfortable saying that humans are primates?
6. Do you have any trouble classifying us as animals?

**Interview 7—Holidays: Religion: Family Habits**
1. Are holidays a big event around your house?
2. What are your plans for Thanksgiving? Christmas?
3. Do you have much homework assigned over Christmas?
4. Will your family be here?
5. What do you usually do Christmas? Like Christmas eve and Christmas day?
6. What church do you go to?
7. So is church a big part of your holiday?

**Interview 8—Biology: Evolution as Biological Theory:**
**Evidence for Evolution:** **Application for Evolution**
1. Tell me what you think biology is.
2. All right, make that definition sound more human, like you were actually talking to someone, explaining biology.
3. Could you give me some of the most important concepts in biology?
4. Ahm, do you use your knowledge that you get in biology class outside of the classroom often? I mean, can you use what you know in everyday life?
5. How? Could you give me some examples?
6. Do you have any pets?
7. Ahm, okay, do you think evolution is an important part of biology?
8. So you think the best part of knowing evolution is just having a general understanding of science?
9. Can you think of evidence that supports evolution? That refutes evolution?
10. Do you think that the theory of evolution has any application to other areas outside of biology?

Interview 9—Age of Earth: Successful Species: Comparison of Species: Predictability of Evolution
1. How old do you think the earth is?
2. Why would you say closer to 4 million?
3. Can you differentiate between [million and billion]? I mean, we're talking about a lot.
4. Do you think they way the earth looks now has changed a lot during that time?
5. Do you see any other changes? I mean, can you think of any other changes that happened?
6. So if you were to look at our world now, then say it is, and then you go forward about a million years from now. What do you think the earth would look like? What kind of changes do you see?
7. Where did you learn all this?
8. You think earth science as a whole is kind of boring? Why?
9. What would you say is a successful species?
10. So how would a species endanger itself?
11. Could you give me an example of that?
12. Would you say that we're in danger of messing ourselves up, I mean humans as a species?
13. What do you think of as a failure of a species?
14. Do you think of extinction as a natural process?
15. Do you think of humans as evolving?
16. Do you think things are getting more perfect as they evolve?
17. What do you mean when you say a species is getting more complex? Can you give an example?
18. If we could start the world over again, I mean the whole thing, and all the same natural events happened, and the same condition existed on this replication of the world as there existed then, do you think that the species that result would be the same as there are now?
19. What term would you use to characterize evolution, operating as an engineer or a tinkerer?

Interview 10—Natural Selection
1. Here's a statement, and I just want you to comment on it, one way or another. If you agree with it tell me why. Or if you disagree with it, tell me why. A man made the statement, "The probability that natural selection could build something as complex as an eye is equal to the probability that a tornado could go through a junkyard and build a 747."

Interview 11-Boundaries of Science, Religion, Philosophy
1. What do you think science allows you to talk about?
2. What do you think philosophy allows you to talk about?
3. How about religion?
4. If you had to group two of those three thing together, science relation, and philosophy, what two do you think are more similar? Why is that?
5. What do you think accounts for the conflict between science and religion?
6. Do you see science and religion as between distinctly separate?
5 Interview 12--Biblical Interpretation
1. So do you think that much of the bible can be treated as an analogy?
2. So, did you figure this out for yourself, or did someone help you with this?
3. When did you decide not to literally interpret the bible?
4. Do you discuss religious and scientific issues with your parents?

Interview 13--Species: Understanding of Evolution
1. Can you tell me what a species is?
2. How can you tell if something is a species?
3. What does the phrase "closely related" mean?
4. Are all dogs one species?
5. How about ducks?
6. Do you think that a species is a natural kind of construct? I mean, is it something that exists in nature?
7. Scientifically, do you know the rules for writing a species name?
8. How is a species related to a population? To a genus?
9. Do you feel more comfortable discussing evolution now, more so than you did at the beginning of the school year?
10. If you were at a party and a bunch of people were discussing evolutionary theory, would you join in the discussion?

Interview 14--Adaptation: Mutation
1. We had talked before about adaptations. What do you think an adaptation is?
2. Could you give me an example of a biological adaptation?
3. Are all adaptations genetic?
4. Is getting a chill bump an example of a genetic adaptation? Why not?
5. Where do initial genetic adaptations come from?

Interview 15--Personal Characteristics: View of Research Process
1. So, are you getting excited about the end of school?
2. What are you going to do this summer before college?
3. Is college a kind of scary thing?
4. Have you ever thought of not going to college?
5. If you didn't go to college, what would you do? What kind of work?
6. Do you like your summer job?
7. Can you give me three phrases that describe your thoughts about U High?
8. Do you think you're getting a good education here?
9. How do you think you learn the best? Under what conditions do you learn the most?
10. Do you parents help you much with your homework?
11. Do you know what your class position is?
12. Do you think your class position is important? Why?
13. What do you think about our research so far?
14. Do you mind talking about yourself?
15. Do you ever feel uncomfortable with my questions?

Interview 16--Competition: Limits of Evolutionary Theory: Differential Reproduction
1. When you think about nature, do you think of it as being very competitive?
2. Can you give me an example?
3. Let's think about it in the context of the 'possum you found yesterday. Could you explain that in competitive terms?
4. What are things competing for? Why do organisms compete?
5. Do you consider humans as being very competitive?
6. When we use the word biological evolution, how do you use the term? Do you use it just to refer to the changes that occur in a species, or does it also refer to the original production of life?

Interview 17--Biology Class
1. So, what did you think of the biology class?
2. Is there anything that you would like me to tell [Hurston] that could improve the class?

B-2: Parent Interview
1. Where do you work?
2. How long have you lived here?
3. How many children do you have?
4. What do they do?
5. Why did you decide to put [your child] in U High?
6. How does a parent go about enrolling their child in U High?
7. Do you think he/she likes it there?
8. If you could come up with three characteristics to describe U High, what would they be?
9. Do you know why your child enrolled in Hurston's biology II class?
10. What do you think she/he wants to do after graduation?
11. How do you feel about your child's career plans?
12. Has she/he always been interested in biology?
13. What are her/his hobbies?
14. Does she/he enjoy school?
15. Do you think her/his interest came from things you might have done as a family?
16. Are you two interested in biology?
17. Does your family watch nature shows on television?
18. Have you discussed what [your child] and I do for my research?
19. What's your opinion of this activity?
20. What are your thoughts on the theory of evolution?

B-3: Principal and Counselor Interview
1. Could you describe your student population?
2. You've said you "stay on top of" many problems with the student body. Do you think you can do that because your classes are a little smaller than the typical school?
3. Do you know if many of your students come from families whose parents attended U High?
4. Can you tell me about the parents that send their kids to school here? Are they very active in school activities?
5. How are curricular decisions made?
6. Do you see it as a good or bad thing that you are linked to a large central office?
7. What are your admission procedures?
8. How many students apply each year?
9. How many can you accept?
10. Who decides which students get in?
11. What are the goals of the school?
12. What factors are considered when hiring teachers?
13. How would you describe the teachers in the science department?
14. What are your impressions of Hurston's biology classes?
APPENDIX C
MATERIALS AND SAMPLES OF INTERVIEW QUESTIONS/DIRECTIONS FOR STRUCTURED INTERVIEW

C-1: Concept Mapping

General Directions for All Maps
1. [The topic statement is given.]
2. Write down some key concepts that you think you need to explain it, then map it.
3. I want you to tell me about those concepts as you list them.
4. I want you to keep it around no more than 10 concepts.
5. Now the next thing, I guess is sort these on you desk in some kind of hierarchy.
6. Now, you’ll need linking words.
7. Read the map for me.

General Questions for All Maps
1. So are you happy with that arrangement?
2. Is that how you would best explain it?
3. So what’s the difference between these branches?

• Concept mapping (CM-1)-directions
  What I want you to do today, the big thing is, is to do a concept map for me.
  And I want you to do it on your understanding of evolution to this point.
• Concept mapping (CM-2)-directions
  I want you do draw a concept map about how evolution works.
• Concept mapping (CM-3)-directions
  Using these five words, (evolution, mutation, change, population, natural selection), I want you to draw a map explaining how evolution works. You can add any terms you need.

C-2: Interview About Instances

Adaptation, Taxonomy, Speciation, Species Concept, Natural History (IAL-1)

In this set of interviews, students were shown drawings and photographs. The students were asked to discuss anything that occurred to them as they observed the graphics.

The graphics used for the first interviews about instances included:
1. A common egret fishing in white, choppy water.
2. A red octopus.
3. An elephant foraging from a tall tree in an otherwise empty field.
4. A litter of kittens, all of which are phenotypically different.
5. Three different bears: a grizzly, a brown bear, and a polar bear.
6. A purple wild flower.
7. A small, black sea turtle, walking over white sand.
8. A fruit eating bat feeding from a cactus.
9. A uniform population of cartoon rabbits.
10. Three different primates: a gorilla, a chimpanzee, a human.
11. A phylogeny of humans including primates from gibbons to humans entitled, "A puzzling family tree."
12. A graphic depicting different species of Galapagos finches, their different bill structures, and food source.

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Sample directions/questions/probing remarks included:
1. What I want you to do is to look at the pictures and describe what you see and anything that pops into your mind about the organism.
2. Do you know anything about that kind of bird?
3. I think it's a common egret.
4. Do you know how they make their living?
5. What do you know about octopuses?
6. Can you think of anything else as you look at that picture?
7. Do you think those dogs are related?
8. What's it mean to be a dog? Are they both dogs? How?
9. Do you know what the term species means?
10. Do you think that all the variation in dogs is a natural thing or something we've done through breeding?

Evolutionary Patterns (IAI-2)

In this set of interviews, students were shown groups of drawings. The students were asked to select the graphic from the group which best depicted what they thought of as evolution and to describe their selection and the reasoning behind this choice.

The sets of graphics included:
1. A. A phylogenetic tree of primates including gibbons, orangutans, gorillas, pigmy chimpanzees, and humans. A member from each of these groups is shown along the top of the graphic with a tree below them showing phylogenetic relationships. The branches from this tree are graphed according to the time scale when the branching occurred.
   B. A line drawing depicting all the major branches of the entire animal kingdom, the result is a kind of bush with organisms at each of it branches. The organisms are depicted as well as their evolutionary relationships. The organisms shown included: ancestral protists, cnidarians, flatworms, roundworms, mollusks, annelids, crustaceans, insects, centipedes, mammals, birds, reptiles, amphibians, fish, tunicates, echinoderms, and sponges.

2. A. Three different butterflies, one at the bottom with an arrow leading to each of the other two which are at the top of the page.
   B. An ancestral glyptodont shown at the bottom of the page with an arrow leading to an armadillo.
   C. A salamander shown at the bottom of the page with an arrow leading up to a toad, which has an arrow leading up to a duck-billed platypus, which has an arrow leading up to a raccoon.

Sample questions for each of these two sets of graphics included:
1. Which one do you think best demonstrates what you think biologist talk about when they talk about evolution?
2. Why did you select that one?

Patterns of Evolutionary Change (IAI-3)

In this set of interviews, students were shown a series of line drawings shown below. The students were asked to select which of the four branches best depicted their ideas of evolutionary change. The students were also requested to explain their reasoning.
Sample questions included:
1. Which tree best depicts evolutionary changes as you understand them?
2. Okay, so why did you pick that one?
3. So what was the deciding factor for you?

C-3: Prediction Interviews

Three series of graphics were used in these structured interviews. The students were the first graphic in the series, with an explanation the situation. Then they were asked to make a prediction based on their observations. This prediction was written down as well as stated verbally. Afterwards, the students were shown the second graphic in that series and they were asked to make observations of the outcome of the situation. Finally, they were asked to explain any differences between their prediction and the outcome of the situation.

Prediction interview for knowledge of genetics (PI-1)
The following were the graphics used and sample questions:
1. Here are two mice, one male and one female. Both of the mice had their tails run over by a cart when they were very young. These two mice mate. What will their offspring look like?

Here are their offspring. Notice they all have long tails. How can you explain this?
2. Here are two mice, one male and one female. Notice one has a normal tail, while the other has no tail at all. This mouse was born without a tail. These two mice mate. What will their offspring look like?

Here are their offspring. Notice that some have long tails and some have no tails at all. How can you explain this?

3. Here are two ducks. Notice the male is black and the female is white. These two ducks have a clutch of offspring. What will their offspring look like?

Here are their offspring. Notice that some are black and some are white. How can you explain this?

Prediction interview for knowledge of mutation (PI-2)
The following were the graphics used and sample questions:
1. The following is a prototypical species of bear. Notice he has short hair and is a ground dweller. The ice age come to the place where this species lives. Of the three possible mutations seen here (becoming a cave dweller, gaining long hair, or losing all hair), which one or ones do you think are possible? Which one or ones are impossible? Why?
All three mutations are possible. How does this coincide with your predictions?

C-4: Sorting Task

For this interview, the students were randomly presented six graphics. They were asked to use these graphics to explain an evolutionary event of color change in a population of rabbits. The students were instructed that they may use any of the card they wished, in any order, and that not all of the cards had to be used. As they were sorting, the students were reminded to talk aloud, and to voice as many of their thoughts as were possible.

Sample questions included:
1. So you think the rabbits pass on this trait of brownness? How?
2. This genetic event, is it in any way tied to the arrival of the hawk?
3. Is there any other way you would like to explain this evolutionary event?
4. When you say dominance, is that a like of genetic dominance?

The graphics were:
In this structured interview, the students were randomly presented a group of cards, each which contained a word. The students were instructed to select the terms which could be applied to evolutionary theory and those terms which could not. The students were reminded to talk as the sorted the terms and they were asked to explain their reasoning.

The terms used included: design, drastic, success, need, random, chance, subtle, and order.

Sample questions included:
1. Why?
2. Is putting order on the outside somehow related to putting chance and random on the inside?

C-6: Drawing

For this structured interview, the participant was asked to "draw the time line of the history of life on earth." After drawing the time line, the participant was asked to explain the time line. Questions were asked after the drawing was made to elicit additional information about the participant’s conception of natural history.

Sample questions included:
1. So, what do you say? What do you think happened?
2. Do you think there was a big time gap like you drew?
3. Speculate for me. What do you think went on in all that time between the beginning of the earth and the origins of the dinosaurs?
4. So that’s something you really don’t care about one way or another?
5. So you would like to think there is just a gradual change from one group to another?
C-7: Bishop and Anderson (1985) Exam

This exam was administered at the beginning and end of the year to all the participants in the class. The exam was administered as published by Bishop and Anderson (1985), except for the final questions. For this question, instead of asking about beliefs, the participants are asked for their opinions. The interview participants were asked to explain their pre- and posttest answers in structured interviews.

Name ______________________

For the following questions, use the lettered statements listed and circle the letter which most closely corresponds to what you understand. Provide written explanations where you feel they are appropriate.

- The statement on the left is the only correct statement.
- The statement on the left is more correct.
- Both statements are equally correct.
- The statement on the right is more correct.
- The statement on the right is the only correct statement.

If none of these fits your understanding, please explain.

Ducks are aquatic birds. Their feet are webbed and this trait makes them fast swimmers. Biologist believe that ducks evolved from land birds which did not have webbed feet.

1. The trait of webbed feet in ducks:

<table>
<thead>
<tr>
<th>Appearance</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appeared in ancestral ducks because they lived in water and needed to swim.</td>
<td>Appeared in ducks because of a chance mutation</td>
</tr>
</tbody>
</table>

2. While ducks were evolving webbed feet:

<table>
<thead>
<tr>
<th>Amount of webbing</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>With each generation, most ducks had about the same amount of webbing on their feet as their parents.</td>
<td>With each generation most ducks had a tiny bit more webbing on their feet than their parents</td>
</tr>
</tbody>
</table>

3. If a population of ducks were forced to live in an environment where water for swimming was not available:

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many ducks would die because their feet were poorly adapted to this environment</td>
<td>The ducks would gradually develop nonwebbed feet</td>
</tr>
</tbody>
</table>

4. The population of ducks evolved webbed feet because:

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>The more successful ducks adapted to their aquatic environment</td>
<td>The less successful ducks died without offspring</td>
</tr>
</tbody>
</table>

Note. This is not the actual exam, but this includes the same questions in the same order as that administered during the research.
5. Biologists often use the term "fitness" when speaking of evolution. Below are descriptions of four male lions. According to your understanding of evolution, which lion would biologists consider the "fittest?"

<table>
<thead>
<tr>
<th>Name</th>
<th>&quot;George&quot;</th>
<th>&quot;Ben&quot;</th>
<th>&quot;Spot&quot;</th>
<th>&quot;Sandy&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>10 feet</td>
<td>8 1/2 feet</td>
<td>9 feet</td>
<td>9 feet</td>
</tr>
<tr>
<td></td>
<td>175 lbs</td>
<td>160 lbs</td>
<td>162 lbs</td>
<td>160 lbs</td>
</tr>
<tr>
<td>Number of cubs fathered</td>
<td>19</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Age of death</td>
<td>13 years</td>
<td>16 years</td>
<td>12 years</td>
<td>9 years</td>
</tr>
<tr>
<td>Number of cubs surviving to adulthood</td>
<td>15</td>
<td>14</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Comments</td>
<td>George is very large, very healthy. The strongest lion.</td>
<td>Ben has the greatest number of females in his harem.</td>
<td>When the area that Spot lived in was destroyed by fire, Spot was able to move his pride to a new area and change his feeding habits.</td>
<td>Sandy was killed by an infection resulting from a cut in his foot.</td>
</tr>
</tbody>
</table>

The "fittest" lion is:

a) George  b) Ben  c) Spot  d) Sandy

Explain your answer:

6. A number of mosquito populations are today resistant to DDT, even though those species were not resistant to DDT when it was first introduced. Biologists believe that DDT resistance evolved in mosquitoes because: (choose the best answer)
   a. Individual mosquitoes built up an immunity to DDT after being exposed to it.
   b. Mosquitoes needed to be resistant to DDT in order to survive.
   c. A few mosquitoes were probably resistant to DDT before it was ever used.
   d. Mosquitoes learned to adapt to their environment.
   e. Other, please explain.

7. Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologists explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run 20 miles per hour?
8. Cave salamanders are blind (they have eyes which are nonfunctional). How would biologist explain how blind cave salamanders evolved from sighted ancestors?

9. What is your personal opinion of evolution?

Sample interview questions for the Bishop and Anderson (1985) exam included:
1. Where did you learn that?
2. What does that mean?
3. So do you think a lot of things just pop up because of mutations?
4. What's do difficult about that question, do you know?
5. What would happen if the ducks were juveniles, like real young?
6. What's natural selection?
7. So how does that happen?
8. Would the mutations have happened without the DDT?
9. Could that immunity be passed on to their offspring?
10. What does fittest mean?
11. What makes [that lion] fittest?
12. How would the cheetahs learn to run faster?
13. Would that be passed on to their offspring?
14. So how did that variation get there in the first place?
APPENDIX D

TEACHING MATERIALS/TEACHING PRACTICES

This appendix is a list of the most common of teaching materials and teaching practices used by Ms. Hurston used throughout her biology II course. The categories of teaching materials and teaching practices are listed in a descending order of their prevalence in Ms. Hurston's teaching. These categories include (1) laboratories, (2) videos and associated media, (3) student readings, (4) journal writing, and (5) student presentations. Listed with the categories are specific assignments, along with the date of the assignment, a rough estimation of the instructional time required by the assignment (if more than one day was commonly required for this the teaching material/practice), and the unit to which each assignment related. Note, the designation of instructional unit is an artificial one, because many assignments could pertain to a variety of teaching topics.

(I) Laboratories

<table>
<thead>
<tr>
<th>Date</th>
<th>Title</th>
<th>Days of instruction</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/19/92</td>
<td>Pipetting and weighing repetitions</td>
<td>1</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nature of science</td>
</tr>
<tr>
<td>8/20/92</td>
<td>Effects of pollution on seed germination</td>
<td>3</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nature of science</td>
</tr>
<tr>
<td>9/4/92</td>
<td>Animal behavior observations</td>
<td>1</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>9/14/92</td>
<td>Meal worm observations</td>
<td>1</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>9/22/92</td>
<td>pH: The measurement of hydrogen ion concentrations</td>
<td>2</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nature of science</td>
</tr>
<tr>
<td>9/23/92</td>
<td>Observations of a mini-pond ecosystem</td>
<td>1</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Animal behavior</td>
</tr>
<tr>
<td>9/29/92</td>
<td>Roly-poly observations</td>
<td>1</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/2/92</td>
<td>Classroom animal observations</td>
<td>1</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/8/92</td>
<td>Animal behavior experiments</td>
<td>1</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/14/92</td>
<td>Zoo animal observations</td>
<td>1</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>11/4/92</td>
<td>Electrophoresis</td>
<td>2</td>
<td>Genetic techniques</td>
</tr>
<tr>
<td>11/13/92</td>
<td>Cloning exercise</td>
<td>1</td>
<td>Genetic techniques</td>
</tr>
<tr>
<td>11/9/92</td>
<td>Pig dissection--external anatomy</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/10/92</td>
<td>Pig dissection--circulatory system</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/11/92</td>
<td>Pig dissection--digestive system</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/12/92</td>
<td>Pig dissection--urogenital system</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/13/92</td>
<td>Pig dissection--respiratory system</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/16/92</td>
<td>Pig dissection--review</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/17/92</td>
<td>Pig dissection--brain and review</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/18/93</td>
<td>Pig dissection--review</td>
<td>2</td>
<td>Anatomy</td>
</tr>
<tr>
<td>11/30/93</td>
<td>Pig dissection--surgery</td>
<td>1</td>
<td>Anatomy</td>
</tr>
<tr>
<td>12/1/92</td>
<td>Litter sampling</td>
<td>1</td>
<td>Laboratory techniques/</td>
</tr>
</tbody>
</table>

337
<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/2/92</td>
<td>Sampling</td>
<td>Nature of science</td>
</tr>
<tr>
<td>1/11/93</td>
<td>Interpreting data and stating conclusions: Owl pellets and plant growth</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nature of science</td>
</tr>
<tr>
<td>1/27/93</td>
<td>Inductive reasoning: Chromatography and observations</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anatomy/ Nature of science</td>
</tr>
<tr>
<td>2/11/93</td>
<td>Microbiology--introduction</td>
<td>Nature of science</td>
</tr>
<tr>
<td>2/12/93</td>
<td>Microbiology--rules, microscope</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td>2/15/93</td>
<td>Microbiology--sterilization</td>
<td>Anatomy/ Nature of science</td>
</tr>
<tr>
<td>2/16/93</td>
<td>Microbiology--media</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td>2/17/93</td>
<td>Microbiology--sterile transfer, aseptic techniques, agar slants, inoculations</td>
<td>Microbiology techniques</td>
</tr>
<tr>
<td>2/18/93</td>
<td>Microbiology--streak plate, techniques</td>
<td>Microbiology techniques</td>
</tr>
<tr>
<td>2/19/93</td>
<td>Microbiology--hay infusion, smear slides</td>
<td>Microbiology techniques</td>
</tr>
<tr>
<td>3/1/93</td>
<td>Microbiology--slide staining, smears</td>
<td>Microbiology techniques</td>
</tr>
<tr>
<td>3/2/93</td>
<td>Microbiology--information on stock cultures</td>
<td>Microbiology techniques/</td>
</tr>
<tr>
<td>3/15/93</td>
<td>A model for neurotransmitter activity in the earthworm</td>
<td>Neurobiology</td>
</tr>
<tr>
<td>3/18/93</td>
<td>Microbiology--catch up day</td>
<td>Microbiology techniques/</td>
</tr>
<tr>
<td>3/19/93</td>
<td>Visual physiology</td>
<td>Microbiology techniques/</td>
</tr>
<tr>
<td>3/31/93</td>
<td>Microbiology--student experiments</td>
<td>Anthropology</td>
</tr>
<tr>
<td>4/1/93</td>
<td>Microbiology--unknowns</td>
<td>Microbiology techniques/</td>
</tr>
<tr>
<td>4/8/93</td>
<td>Introduction to statistics</td>
<td>Laboratory techniques/</td>
</tr>
<tr>
<td>4/13/93</td>
<td>Anthropology--Anthropometry: Standard techniques for measuring human beings</td>
<td>Anthropology</td>
</tr>
<tr>
<td>4/15/93</td>
<td>Anthropology--Fingerprints in humans: An aspect of variation</td>
<td>Anthropology</td>
</tr>
<tr>
<td>4/19/93</td>
<td>Anthropology--Characteristics of evolution: Patterns of change</td>
<td>Anthropology</td>
</tr>
<tr>
<td>4/21/93</td>
<td>Anthropology--Identification of age, sex, race and size of skull, skeleton, and cardboard cutout</td>
<td>Anthropology</td>
</tr>
<tr>
<td>4/27/93</td>
<td>Anthropology--Primates: Classification and morphology</td>
<td>Anthropology</td>
</tr>
</tbody>
</table>
### (2) Student Reading

<table>
<thead>
<tr>
<th>Date</th>
<th>Title</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/14</td>
<td>Forensic Anthropology</td>
<td>Anthropology</td>
</tr>
</tbody>
</table>
Anthropology

4/23  Witness for the prosecution: DNA fingerprinting
Anthropology

Anthropology

Anthropology

5/2  Shipman, Pat. (1986). Baffling limb on the family tree. Discover, September, 87-93.
Anthropology

5/3  Chapter 4: Preliminary. Sherry Demastes

Total-20 student reading

(3) Videos and associated media

<table>
<thead>
<tr>
<th>Date</th>
<th>Titles</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/21/92</td>
<td>&quot;Galapagos Islands&quot;</td>
<td>Dinosaurs</td>
</tr>
<tr>
<td>9/2/92</td>
<td>&quot;The Great Dinosaur Hunt&quot;</td>
<td>Dinosaurs</td>
</tr>
<tr>
<td>9/9/92</td>
<td>&quot;The Case of the Flying Dinosaur&quot;</td>
<td>Dinosaurs</td>
</tr>
<tr>
<td>9/15/92</td>
<td>&quot;People of the Forest&quot;</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>9/18/92</td>
<td>&quot;Life of an Urban Gorilla&quot;</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>9/25/92</td>
<td>&quot;Mountain Gorillas&quot;</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/9/92</td>
<td>&quot;Family of Chimps&quot;</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/19/92</td>
<td>&quot;So Like Us&quot;</td>
<td>Animal rights/</td>
</tr>
<tr>
<td>10/21/92</td>
<td>&quot;From Monkeys to Apes&quot;</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/26/92</td>
<td>&quot;Nature Watch&quot;</td>
<td>Animal rights</td>
</tr>
<tr>
<td>10/27/92</td>
<td>&quot;Wildlife Journey&quot;</td>
<td>Animal rights</td>
</tr>
<tr>
<td>11/19/92</td>
<td>&quot;Cats: Caressing the Tiger&quot;</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>12/7/92</td>
<td>&quot;Human Tissue Implants&quot;</td>
<td>Genetic techniques</td>
</tr>
<tr>
<td>1/7/93</td>
<td>&quot;The New Genetics: Rights and Responsibilities&quot; (film strip)</td>
<td>Genetic techniques</td>
</tr>
<tr>
<td>1/11/92</td>
<td>&quot;On the Shoulders of Giants&quot;</td>
<td>Evolution/ Nature of science</td>
</tr>
<tr>
<td>1/20/93</td>
<td>&quot;Patterns and Processes (video disk)</td>
<td>Evolution</td>
</tr>
<tr>
<td>1/22/93</td>
<td>&quot;The Shape of Things&quot;</td>
<td>Evolution</td>
</tr>
<tr>
<td>3/12/93</td>
<td>&quot;Wonders of the Brain&quot;</td>
<td>Neurophysiology</td>
</tr>
<tr>
<td>4/12/93</td>
<td>&quot;The Mysteries of Mankind&quot;</td>
<td>Anthropology</td>
</tr>
</tbody>
</table>

Total--20 videos/filmstrips/video disks.
(4) Student journals

<table>
<thead>
<tr>
<th>Date</th>
<th>Assignment</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/1/92</td>
<td>Sex, Drugs, Disasters, etc. Stop. Write a journal type response to that plus the discussion we had about the &quot;Dinosaurs on Mars&quot; article.</td>
<td>Nature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Science/Dinosaurs</td>
</tr>
<tr>
<td>9/18/92</td>
<td>Write down some behavioral characteristics of the chimpanzees and gorilla that were behavior unexpected by you.</td>
<td>Animal</td>
</tr>
<tr>
<td>9/21/92</td>
<td>How have your attitudes about the great apes changed?</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>9/30/92</td>
<td>Reports of your readings. What methods did they use? How long did the study last? Give some information about the animal Explain what was learned by the study</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/12/92</td>
<td>(Written after an oral reading of Through a Window, J. Goodall). Which one, play or war, played a bigger role in the evolution of man?</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>10/19/92</td>
<td>(Written after an oral reading of Through a Window, J. Goodall). What does this window have to do with biology?</td>
<td>Animal behavior</td>
</tr>
<tr>
<td>11/18/92</td>
<td>Write how the anatomy of the pig relates to other animals dissected in other classes. Tell how studying the pig anatomy will benefit your understanding of human anatomy.</td>
<td>Dissection</td>
</tr>
<tr>
<td>12/3/92</td>
<td>Describe the pathway or the evolutionary process that lead to human having an appendix and pigs having a cecum.</td>
<td>Anatomy/Evolution</td>
</tr>
<tr>
<td>1/25/93</td>
<td>What does &quot;the Shape of Things&quot; video have to do with evolution?</td>
<td>Evolution</td>
</tr>
<tr>
<td>2/9/93</td>
<td>Summary of essay. What is the organism it was about or what action? What was the point of the essay? (The author's messages it were) What is the value of a scientific essay?</td>
<td>Nature of Science</td>
</tr>
</tbody>
</table>

Total--10 student journal entries.

(5) Student Presentations

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Single or Group Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/8</td>
<td>Reporting behavioral observations</td>
<td>S(Single)</td>
</tr>
<tr>
<td>9/11</td>
<td>Summaries of Journal Articles</td>
<td>S</td>
</tr>
<tr>
<td>10/15</td>
<td>Report of Zoo Observations</td>
<td>S</td>
</tr>
<tr>
<td>10/27</td>
<td>Animal Rights Debate</td>
<td>G(Group)</td>
</tr>
</tbody>
</table>
12/7 Summary of Journal Articles S
12/7 Explanation for Personal Checks G
1/8 Moral Crisis in Genetics G
2/1 Book Reports S
2/8 Human Behavior Observations S
4/21 Skeleton Assessment G

Total--10 student lead presentations of material
APPENDIX E

LIST OF ALL EXAM QUESTIONS

First Quarter Exam
Answer the following questions (in complete sentences, with correct grammar and spelling, of course) in 1/2 to 1 page each.

1. Describe some of the ways in which scientist study animals, and explain why anthropomorphism is a danger to their research.
2. Read the Gould essay "The Lessons of The Dinosaurs" and focus on the next to the last paragraph. Discuss both the inevitability of extinction and your personal ideas about the extinction of dinosaurs.
3. What is science, and what are some things to keep in mind when planning an experiment?
4. (Bonus) From either articles you've read or videos you've seen, pick one fact about animal behavior that has given you a new outlook, perspective, or attitude and explain how you have changed your mind and why. (1/4-1/2 pg.)

Anatomy Laboratory Practical
[This was a practical laboratory exam in which students had to identify approximately 30 structures of the fetal pig anatomy.]

First Semester Final Exam
1. There are many controversies or differences of opinion about dinosaurs and their history. Discuss one of the controversial issues, explaining both sides and tell in your personal stance. (1/2-1 page)
2. Describe some of the different methods of studying animals. What are two similarities and two differences between primate behavior and that of Homo Sapiens [sic]?
3. What were the most useful method of studying a primate at the zoo, and why? What were the most interesting things you learned by your own observations? (approx. one page.)
4. Read the attached article and write a short critique of it. (Skip the summary.) What is the importance of this article? (1/4-1/2 page)

Second Semester Final Exam
Day One
Write on separate papers, using correct grammar and spelling. Answer each question thoroughly.
1. What do you think are the most important ideas, themes, concepts, or theories in biology and why? (This question should take 1-2 pages to answer.)
2. What is the importance of measurements to biologists? We can perhaps understand how an engineer building a bridge needs to use careful measurements, but in biology it isn't that critical, is it? (1/4-1/2 page)
3. Of what value is an understanding of statistics and probability to a scientist or an ordinary citizen?
4. Look at the cartoon below and describe what real evolutionary concept are included in it. (1/4-1/2 page)
Day Two

Answer the questions completely on a separate piece of paper, using correct grammar and spelling.

1. A. Give you critique of this course, commenting on the various units and activities. Tell your favorite and least favorite parts, as well as what you perceive to be the strong points and weak points of the course. B. If you were going to design a Biology II course, what would include, and why? (1-2 pages)

2. Suppose a number of U High students came down with a bacterial infection, and it was suspected that the source of infection was at school. Tell how you would investigate to determine possible sources of contamination, test them, and recommend procedures to stop the spread of the infection without shutting down the school. (1/2-1 page)

3. Our State Police Crime lab guide described forensic science as comparing unknowns to knowns. Explain what he meant, and tell if and how this relates to the rest of science. (1/2-1 page)
## APPENDIX F

### INSTRUCTIONAL EPISODE IN EVOLUTION LISTED BY ORDER OF OCCURRENCE

<table>
<thead>
<tr>
<th>Unit</th>
<th>Date</th>
<th>Instructional Method</th>
<th>Title/subject of instruction</th>
<th>Aspect of evolution addressed</th>
<th>Class participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of science</td>
<td>8/17/92</td>
<td>Examination</td>
<td>Bishop and Anderson exam</td>
<td>Natural selection</td>
<td>Individual</td>
</tr>
<tr>
<td>Nature of science</td>
<td>8/21/92</td>
<td>Video</td>
<td>Darwin and the Galapagos Islands</td>
<td>Historical aspect of evolutionary theory</td>
<td>Whole</td>
</tr>
<tr>
<td>Dinosaurs</td>
<td>8/25/92</td>
<td>Discussion-loose triadic dialogue</td>
<td>Being a scientist</td>
<td>Evidence for evolution</td>
<td>Whole</td>
</tr>
<tr>
<td>Dinosaurs</td>
<td>8/25/92</td>
<td>Reading</td>
<td>&quot;Did comets kill the Dinosaurs&quot;</td>
<td>Disaster theory</td>
<td>Individual</td>
</tr>
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<td>Dinosaurs</td>
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5 Note: Instructional method shown in bold had evolution as the focal point of instruction.

6 Note: Complete references for readings can be found in Appendix A.
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Anthropology 4/13/93 Laboratory: "Fingerprints in humans: An aspect of variation" Function of human adaptations: Whole Small group

Anthropology 4/21/93 Discussion-loose triadic dialogue: Fingerprint laboratory Evolution of fingerprints: Whole Small group

Anthropology 4/22/93 Laboratory: "Primates: Classification and morphology" Function of human adaptations: Whole Small group

Anthropology 4/23/93 Discussion--loose triadic dialogue: Primate laboratory Classification and taxonomy: Species concept: Whole Small group

Anthropology 4/29/93 Laboratory: "Evolution: Patterns of change" Convergence, divergence, adaptive radiation, extinction: Whole Small group

Anthropology 4/30/93 Reading: "The data game" Theories of human lineage: Whole Individual

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Theories of human lineage:
- Individual
- Whole
- Small group
APPENDIX G
PARTICIPANTS' CONCEPT MAPS

Brian's Concept Maps

Brian's CM-1, initial

Brian's CM-2, initial

Brian's CM-2, mid-year
Brian's CM-2, year-end

Adaptation

Evolution

Change in species

Mutation

New species

Change in genes

Brian's CM-3, mid-year

Natural Selection

Allows evolution of mutations which
altering genetic DNA structure

If from a new breed

Brian's CM-1, year-end

Creation

Evolution

Species

Mutation in species

Creation evolving to form a new species

Tracing the origins of a species.
Stephanie's Concept Maps

Stephanie's CM-1, initial

Stephanie's CM-2, initial

Stephanie's CM-2, mid-year
Stephanie's CM-3, mid-year

Evolution

- caused by
  - mutation
    - which creates change
      - in the population
      - through Natural selection
        - theory of
          - "Survival of the Fittest"
            - "The desired traits are passed on"

Stephanie's CM-1, year-end

Evolution

- Charles Darwin
  - who discovered
    - from Galapagos Islands

Evolution

- Galapagos Islands
  - which leads to
    - Natural selection
      - which aids evolution
  - aids evolution

Stephanie's CM-2, year-end
Tyler's Concept Maps

Tyler's CM-1, initial

Evolution

Tyler's CM-2, initial

Evolution

begin with creatures put on earth

and the fitted survived the survivors

and unfit died

Tyler's CM-2, mid-year

drawns complexity humans
Tyler's CM-3, mid-year

Evolution

Natural Selection

Population

Change
Mutations

Tyler's CM-1, year-end

Evolution started with creation. It is a change that happens through reproduction involving mutations and natural selection.

Tyler's CM-2, year-end

Evolution is change over time in a species leading to new minor complexity.
Meredith's Concept Maps

Meredith's CM-1, initial

Meredith's CM-2, initial

Meredith's CM-2, mid-year
VITA

Sherry S. Demastes was born in New Field, New York in September 5, 1962. She is the youngest child of Stan and Nan Southerland. Her early summers spent outdoors catching dragonflies with her three brothers and their vacations in the farms of North Florida may explain her great fondness for biology. She received her B.S. in Biology (1983) and M.S. in Zoology (1985) from Auburn University. Her thesis was a physiological ecology problem comparing the metabolic overwintering strategies of two sympatric species of insects.

Lawrence C. Wit, Sherry's major professor at Auburn, not only taught her physiology, but shared with her his great love of teaching. Dr. Wit provided Sherry a wonderful example of what it means to be an excellent science teacher. Her love of teaching is partly due to his enthusiasm and craftsmanship. In addition to teaching in graduate school, Sherry has taught Biology at Southern University and a myriad of biological subjects at Manatee Community College. Currently, she is teaching the high school science courses at East Iberville High School.

Sherry is married to her Physics laboratory partner (James Demastes), and they live in Baton Rouge with their two cats, Hannah and Mighty Joe, Sheila the guinea pig, and Elmo.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Sherry S. Demastes

Major Field: Education

Title of Dissertation: Factors Influencing Conceptual Change in Evolution:
A Longitudinal, Multicase Study

Approved:

[Signature]
Major Professor and Chairman

[Signature]
Dean of the Graduate School

EXAMINING COMMITTEE:

[Signature]
[Signature]
J. C. Williams

Date of Examination: December 6, 1993