College Biology Students' Conceptions Related to the Nature of Biological Knowledge: Implications for Conceptual Change.

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COLLEGE BIOLOGY STUDENTS' CONCEPTIONS RELATED TO
THE NATURE OF BIOLOGICAL KNOWLEDGE: IMPLICATIONS
FOR CONCEPTUAL CHANGE

A Dissertation

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

in

The Department of Curriculum and Instruction

by

Gloria M. Ameny
B.V.M, Makerere University, Kampala, Uganda, 1986
M.S., Louisiana State University, 1994
May 1999

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DEDICATION

To my parents, the late Dr. John Y. Odomoch and Mrs. Terofaina Odomoch, and my three children, Sandra Arao Ameny, Andrew Pascal Ameny, and Sheila Akello Ameny.
ACKNOWLEDGEMENTS

I would like to acknowledge the contributions of several persons whose encouragement, inputs, and criticisms shaped this work. First and foremost, I am most indebted to Dr. Ron Good, my major professor for his guidance and mentorship throughout this program. I could not have learned from a better mentor the openness, selflessness, and constructive criticisms I received from Professor Ron Good. I am greatly honored to have been supervised by this great science educators of our time.

Secondly, I thank all the members of my committee. Dr. Catherine Cummins and Dr. Jim Wandersee from the Department of Curriculum and Instruction for their generous inputs during the planning, prospectus, and final stages of this study. Dr. Dominique G. Homberger from the Department of Biological Sciences for her input, for serving on my doctoral committee, and for allowing me to work with students in her comparative anatomy class. And Dr. John Larkin for allowing me to work with students in his introductory biology class. I also acknowledge all the introductory biology and advanced zoology students who volunteered to be part of this study.

Lastly but not least, I acknowledge Dr. Michael Fitzsimmons of the Museum of Natural Sciences for his inputs during the early stages of this study, Dr. Timothy Gilbertson of Pennington Biomedical Research Center for serving as my graduate school dean's representative, and Dr. James Geaghan of the Department of Experimental Statistics for the technical assistance he provided during the statistical analysis of all quantitative data.
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ABSTRACT

Adequate understanding of the nature of science is a major goal of science education. Understanding of the evolutionary nature of biological knowledge is a means of reinforcing biology students' understanding of the nature of science. It provides students with the philosophical basis, explanatory ideals, and subject matter-specific views of what counts as a scientifically-acceptable biological explanation. This study examined 121 college introductory biology and advanced zoology students for their conceptions related to the nature of biological knowledge. A 60-item Likert-scale questionnaire called the Nature of Biological Knowledge Scale and student interviews were used as complementary research instruments.

Firstly, the study showed that 80-100% of college biology students have an adequate understanding of scientific methods, and that a similar percentage of students had learned the theory of evolution by natural selection in their biology courses. Secondly, the study showed that at least 60-80% of the students do not understand the importance of evolution in biological knowledge. Yet the study revealed that a statistically significant positive correlation exist among students' understanding of natural selection, divergent, and convergent evolutionary models.

Thirdly, the study showed that about 20-58% of college students hold prescientific conceptions which, in part, are responsible for students' lack of understanding of the nature of biological knowledge. A statistically significant negative correlation was found among students' students' prescientific
conceptions about basis of biological knowledge and nature of change in biological processes, and their understanding of natural selection and evolutionary models. However, the study showed that students' characteristics such as gender, age, major, or years in college have no statistically significant influence on students' conceptions related to the nature of biological knowledge.

Only students' depth of biological knowledge or course was found to have a statistically significant influence on students' conceptions related to scientific methods, the scope and limits of biological knowledge, the importance of evolution in biology, and students' understanding of homologous and analogous structural features as products of divergent and convergent evolutionary processes. Findings of this study have implications for college biology teaching, student learning, and conceptual change among college biology students.
CHAPTER 1: INTRODUCTION

Adequate understanding of the nature of science is emphasized in *Benchmarks for Science Literacy* (AAAS, 1993), the *National Science Education Standards* (NRC, 1996), and *Science for All Americans* (Rutherford & Ahlgren, 1990) as a major goal of science education. The National Academy of Sciences in *Teaching about Evolution and the Nature of Science* (NAS, 1998) emphasizes the teaching of evolutionary biology for two reasons. First, as a means of promoting student's understanding of the nature of science. Secondly, as a means of reinforcing students' learning of science as a way of knowing.

The Biological Sciences Curriculum Studies in *Developing Biological Literacy* (BSCS, 1993) describes the theory of evolution by natural selection is the unifying principle of biological knowledge. Adequate understanding of evolutionary concepts is described as fundamental for understanding the relationships among extinct and living organisms, interactions among living organisms, and between living organisms and their physical environment.

In this study, students’ understanding of the nature of science was examined among 121 college students registered in an introductory biology and an advanced zoology course, namely, comparative anatomy. Twenty students, 10 from each class were interviewed to probe further their responses to the questionnaire to investigate their explanations related to the nature of biological knowledge. This was achieved through probing their general understanding of biology, evolutionary concepts, homologous, and analogous anatomical features as products of divergent and convergent evolution.

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Nature of Science

An adequate understanding of the nature of science continues to be a major goal of science education (AAAS, 1993; Rutherford & Ahlgren, 1990). This goal includes understanding of science as a way of knowing, the "modus operandi" of effective science learning. Understanding science as a way of knowing is also an integral part of scientific literacy (Moore, 1993). In the 1996 Proceedings of the National Academy of Sciences the nature of scientific knowledge is described very succinctly in the following statement:

"Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world" (p.2).

The American Association for the Advancement of Science in Science for All Americans (Rutherford & Ahlgren, 1990) and Benchmarks for Science Literacy (AAAS, 1993) describe adequate understanding of the nature of science as understanding the basic beliefs and attitudes that scientists share about the natural world and of what scientists do to understand the world. The National Research Council in the National Science Education Standards describes adequate understanding of the nature of science as understanding of the scientific concepts and processes required for making personal and public decisions.

Scientific knowledge is described as distinguishable from non-scientific ideas because science is based on experimental or observational evidence about nature. Lederman and Zeidler (1987), in a summary of various nature of
science research studies concluded that despite the various definitions associated with the nature of science, adequate understanding of the nature of science simply means understanding the inherent assumptions in the development of scientific knowledge. Smith, Siegel, and McInerney (1997) showed that a reasonable consensus exists among scientists and philosophers on the principal nature of science elements that are appropriate for science instruction in spite of differences that depend on disciplinary perspectives of scientists and philosophers of science.

This lack of agreement on the definition of the nature of science within the nature of science research dictated that the present study be conducted within the discipline of biological sciences. College biology students' understanding of the nature of science was approached from an evolutionary biology and comparative anatomical perspective to allow meaningful interpretation of students' responses and interpretations about the nature of biological knowledge. The decision to conduct the study within the biological sciences was also consistent with suggestions made by Wandersee and Roach (1998), in which the two researchers suggest that nature of science research should be conducted within discipline-specific knowledge domains. This allowed for consideration of the suppositions, assumptions, methods and theories students used to validate specific scientific claims.

Involvement of only college students registered in an introductory biology and an advanced zoology course also allowed the researcher to probe students' understanding of the biological concepts they had learned. Toulman
(1972) describes concepts in learners' conceptual frameworks as what determine how learners understand and explain natural phenomena. Toulman (1972) referred to these concepts which govern development of learners' conceptual understanding of what is being learned as their "conceptual ecology". This study indirectly examined conceptual change among college biology students by examining their conceptual ecology. Conceptual change was reflected in students' ability to accept and choice to use appropriate or scientifically-acceptable concepts from their conceptual ecology to explain biological phenomena they were presented with. Gunstone and White (1992) who refer to studies which examine students' conceptual framework by "probing students' understanding" as a means to improve classroom teaching.

**Nature of Science, Evolution, and Biological Knowledge**

It is a well known fact that biological knowledge is a multidimensional and multilayered type of scientific knowledge (BSCS, 1993). Meaningful research on students' understanding of the nature of biological knowledge requires an examination of their understanding of the interactions, relationships, and interconnections among biological systems and the physical environment within which the systems are found (Hurd, 1993). Adequate understanding of the nature of biological knowledge has been described as understanding the evolutionary history of biological systems, and how the systems interact with each other and with their environment.

Research on students' understanding of the nature of biological knowledge, therefore, requires an investigation of students' understanding of
the evolutionary history of biological phenomena including the thinking and explanatory models used by students to explain biological change over time. The National Academy of Sciences in Teaching about Evolution and the Nature of Science (NAS, 1998), supports the teaching of the evolutionary nature of biological knowledge in all high school and college biology curricula for two reasons. The first function of the teaching of the evolutionary nature of biological knowledge is that it reinforces the learning of science as a way of knowing. Explanations about the natural world are understood as based primarily on empirical evidence, observable or testable data. The second function is that it offers a superb opportunity to illuminate the nature of science, by helping people to differentiate science from other forms of human endeavor or understanding.

In this study, an investigation of students' conceptions of the nature of biological knowledge was conducted through probing students' understanding of the general nature of biology, evolutionary biology, and evolutionary models that are used to study similarities and differences among organisms. The study also attempted to identify students' existing conceptions about the nature of biological knowledge and to identify relationships among students' conceptions and how such conceptions influence students' "grand conceptual schema" related to the nature of biological knowledge.

The goals of the study were consistent with the recommendations made by over 45 biologists, science educators, and science teachers in the Proceedings of the 1992 Evolution Education Research Conference (Good et
al., 1992) that: "understanding how students grapple with the existence and mechanisms of the evolution of life should be a goal as central to science (biology) education as Darwinian evolutionary theory is to biology itself" (p.72). Students' conceptions related to the general nature of biological knowledge was the focus of this study.

Students' conceptions examined included students' understanding of the origin and nature of the changes that occur in living organisms. It also included students' knowledge of the evolutionary processes responsible for such changes, and of homologous and analogous anatomical features as products of evolutionary processes.

**Research Questions**

This study was, therefore, conducted to examine college biology students at Louisiana State University, Baton Rouge Campus for their conceptions related to the nature of biological knowledge through answering the following primary and secondary research questions.

**Primary Research Questions**

1. What conceptions related to the general nature of biological knowledge do college introductory biology and advanced zoology students hold?
2. What conceptions related to the knowledge of evolutionary biology do college introductory biology and advanced zoology students hold?
3. What conceptions related to the knowledge of homologous and analogous anatomical features do college introductory biology and advanced zoology students hold?
Secondary Research Questions

1. How do college introductory biology and advanced zoology students' conceptions of the nature of biological knowledge relate to their knowledge of evolutionary biology and knowledge of homologous and analogous anatomical features?

2. Do course, students' age, gender, or years in college influence college biology students' conceptions related to the nature of biological knowledge?

The design of the study, discussion of results, and interpretation of the findings were conducted in accordance with suggestions made by nature of science researchers, and on the basis of the meanings associated with the following terminologies derived from literature on the philosophy of biological knowledge.

Definitions of Terminology Used in Study

Science - Empirical and logical study of nature, or empirical knowledge derived from a logical study of the natural world.

A scientific theory - Scientific explanation of a natural or biological event or phenomenon.

Biological knowledge - A multidimensional or multilayered knowledge about the living world resulting from logical study of the evolutionary history, relationships, and interactions among living organisms.

NOBKS Questionnaire - The 60-item Likert-scale questionnaire instrument used in this study to quantitatively assess students' conceptions related to the nature of biological knowledge.
**Conceptual ecology** - Concepts in an individual conceptual framework which influence whether or not a learner will understand, accept, or select to use a new concept.

**Conceptual change** - Learning as a fundamentally rational activity in which a learner comes to comprehend and accept new ideas because they are seen as intelligible, plausible, and fruitful in solving other related problems.

**Prescientific conceptions** - Used as a misconception or alternative conception terminology in this study in relation to the nature of the explanation provided for, not the scientific methods used to derive knowledge about a biological phenomenon.

**Natural selection** - The primary mechanism for evolutionary change.

**Speciation** - The process and models used to explain species multiplication.

**Homologous features** - Structural or behavioral characteristics shared by two or more species of living organisms with a common evolutionary history.

**Homologous anatomical features** - Structural features in two or more species of organisms which are traceable to a similar structural feature in their intermediate ancestral species.

**Analogous features** - Functional or physiological characteristics shared by two or more species of organisms living in the same environment, but with different evolutionary histories.

**Analogous anatomical features** - Structural features in two or more species of organisms which are not traceable to a similar feature in their intermediate ancestral species.
Scientific knowledge is universal, derived through systematic study of patterns occurring in nature (AAAS, 1990, p.2)

Knowledge is a result of integrative reconciliation of two or more concepts allowing for new propositions to be made while conflicting meanings are resolved (Ausubel, Novak & Hanesian, 1979)

Biological knowledge has a dual nature. One that is a process, and the other that is a product of knowing (Moore, 1984)

Theories:
3. Conceptual change theory (Posner, Strike,Howson & Goltzog, 1982)

Principles:
Evolution is the unifying principle of biological knowledge. Its understanding is believed to be necessary for making connections among all other biological principles (AAAS,1993; SCS, 1993, NAS, 1998, NRC,1996).

Concepts:
Nature of Science, nature of biological knowledge, evolutionary concepts, divergent and convergent evolutionary models, homologous and analogous anatomical features.

Primary Research Questions:
1. What conceptions of the nature of biological knowledge do college introductory biology and advanced zoology students hold?
2. What conceptions related to knowledge of evolutionary biology do college introductory biology and advanced zoology students hold?
3. What conceptions related to knowledge of homologous and analogous features do college biology students hold?

Secondary Research Questions:
1. How do students' conceptions of the nature of general biological knowledge relate to their knowledge of evolutionary biology and knowledge of homologous and analogous anatomical features?
2. How do course, age, gender, major, or years in college influence students' conceptions related to the nature of biological knowledge?

Researchers Methodology (Doing):
Possible Value Claim: The findings of this study will have far reaching implications for learning, instruction, and conceptual change.

Possible Knowledge Claim: Students' conceptions and understanding of the theory of evolution by natural selection, and of evolutionary history of homologous and analogous features influence their conceptions of biology.

Transformations:
1. Descriptive Statistical Analysis,
2. Factor analysis to extract factors representing students' conceptions,
3. Pearson's correlation analysis on extracted factors,
4. Multivariate analysis of variance,
5. Content analysis of interview responses.

Records:
1. Categorical numerical data from the NOBKS questionnaire.
2. Student interview responses

Events and Objects
1. Students responding to the NOBKS questionnaire.
2. Students responding verbally and in writing to interview questions.

Figure 1: Gowin's Vee Diagram of Study
CHAPTER 2: REVIEW OF LITERATURE

Theoretical Basis of Research

There is increasing evidence that meaningful learning of declarative knowledge, procedural knowledge, and reasoning skills involves a process of restructuring of new knowledge through modification of existing knowledge. Conceptual restructuring can only occur when a rational method of model revision on what is being learned is applied by the learner. With these assumptions in mind, the present study was guided by three learning theories, namely, Ausubel's cognitive theory (Ausubel, Novak & Hanesian, 1978), Ausubel-Novak-Gowin's theory of meaningful learning (Novak & Gowin, 1984), and Posner, Strike, Hewson & Gertzog's (1982) conceptual change theory.

Ausubel's Cognitive Theory

Ausubel's cognitive theory states that every learner's cognitive structure is hierarchically organized, and that during learning concepts undergo processes of modification, progressive differentiation, and integrative reconciliation (Ausubel, Novak & Hanesian, 1978). The idea of hierarchical structure of cognition incorporates Ausubel's principle of subsumption.

Ausubel's Principle of Subsumption

Under the principle of subsumption, new information is described as being relatable to and subsumable under more general, more inclusive concepts. Learning is enhanced when a good hierarchical structure for a segment to be learned begins with broad inclusive concepts and is organized progressively into more specific, less inclusive concepts. Hierarchy also
suggests that there is a progressive differentiation of concepts and formation of specific conceptual interrelationships within the learner's cognitive framework as described in Ausubel's principle of progressive differentiation.

**Ausubel's Principle of Progressive Differentiation**

Ausubel's principle of progressive differentiation states that meaningful learning is a continuous process in which new concepts gain greater meaning as new relationships and propositional links are acquired. This principle assumes that progressive differentiation is a result of identification of regularities in the concepts being learned. Learning becomes a reorganization of meanings associated with concepts or propositions in the learner's cognitive structure. The meaning a learner associates with any given concept becomes dependent on the number of relevant relationships perceived and the relationships among the concepts in a learner's conceptual framework.

The hierarchical nature of the learner's cognitive structure permits differentiation of concepts from general to specific ones. In the present study, students' explanations of the biological concepts and processes were used as probes to tap into their conceptual framework. Students' responses and verbal explanations became a measure of how well students had modified their existing conceptions during the period of learning. Students' responses to the NOBKS questionnaire and interview questions became a measure of how well the students had reconciled their own meanings of nature and biological phenomena with the meanings they have acquired during learning as explained by Ausubel's principle of integrative reconciliation.
Ausubel's Principle of Integrative Reconciliation

Ausubel's integrative reconciliation principle of learning states that learning occurs when two or more concepts are recognized as related to a new propositional meaning. This principle of learning assumes that conflicting meanings of concepts are resolved through integrative reconciliation within a learner's conceptual framework. This process is similar to Piaget's process of assimilation (Piaget, 1970). Explanations a learner provides externalize his/her conceptual framework and reflect existing conceptions in the learner's conceptual framework.

Explanations also reflect existing and missing conceptual linkages in a learner's conceptual framework. Persistence of lack of scientifically-acceptable explanations suggest presence of misconceptions. The alternative conceptions terminology used throughout this study for such misconceptions is prescientific conceptions. Introductory biology and advanced zoology students' conceptual frameworks and prescientific conceptions students hold in relation to biological processes were identified during the study by means of a researcher-developed NOBKS questionnaire and student interviews.

Theory of Meaningful Learning

Novak and Gowin (1984) adopted Ausubel's cognitive theory to explain the theory of meaningful learning. This theory, also referred to as Ausubel-Novak-Gowin's theory, states that "the most important single factor influencing learning is what the learner already knows; ascertain this and teach the learner accordingly" (p.97). Novak and Gowin (1984) described meaningful learning as
dependent on what the individual learners already know. The ability to recognize what one knows is also called the process of metacognition. Through use of metacognitive skills students seek new forms of knowledge if they are not satisfied with the intuitive available explanations. Meaningful learning requires a rational analysis of alternative conceptions during learning (Posner, Strike, Hewson & Gertzog, 1982). Scientifically acceptable knowledge is built on a learner's existing conceptions (Novak & Gowin, 1984).

Meaningful learning is described as requiring a conscious awareness of new relationships between new and old sets of concepts (Novak & Gowin, 1984). When a substantial alteration in concept meaning has occurred, the resulting awareness of the new relationships produces the "ah ha" feeling, and the learner suddenly recognizes a new meaning. The learner begins to develop conceptual change as new meanings are associated with existing concepts. This implies that for conceptual change to occur a learner must consciously identify and rationally replace misconceptions in his or her conceptual framework with new propositional linkages among the concepts present in his or her conceptual framework. The rational steps taken by the learner to acquire scientific knowledge are best explained by the conceptual change theory described by Posner, Strike, Hewson and Gertzog (1982).

**Conceptual Change Theory**

Conceptual change theory states that a learner's major organizing conceptions undergo a process of holistic change as a new conception is judged as being more intelligible, plausible, and fruitful than the preceding or
competing conceptions (Posner, Strike, Hewson & Gertzog, 1982). The expanded conceptual change model explains conceptual restructuring and learning as a rational model-revising, and application of problem solving strategies (Posner & Strike, 1985). The conceptual change model emphasizes the kind of evidence needed to rationally direct conceptual change among learners such as those in college science and biology classrooms. Four conditions explained on the following page are believed to be necessary for conceptual restructuring to occur among learners.

1. There must be a dissatisfaction with the existing conceptions. Learners are likely to make major conceptual changes only when they believe that less radical changes will not work.
2. The new conception must be minimally understood. The learner must be able to grasp how experience is structured sufficiently by a new conception in order to agree to explore the possibilities inherent in it.
3. The new conception must appear initially plausible and have a capacity to solve problems generated by its predecessors, and fit with other knowledge, and experience otherwise it will not appear a plausible choice.
4. The new conception must suggest possibility of a fruitful research program. It should have a potential of being extended and open to new areas of inquiry.

Students may not recognize the importance of the evolutionary theory for understanding the nature of biological knowledge unless they have a
conceptual understanding of the process of natural selection. The theory of evolution by natural selection fulfills all the four conditions in the conceptual change model. Initially, it is poorly understood by most students (Keown, 1988; Brumby, 1984; Bishop & Anderson, 1990; Cummins, 1992). However, when students recognize its plausibility and ability to solve problems generated within all the biology disciplines including genetics, anatomy, physiology, or biochemistry then students suddenly attain the "ah ah" feeling. After this students often want to learn more about it in a meaningful way. Learners also begin to weigh the theory's intelligibility against those of alternative theories associated with the origin of life and biodiversity.

Use of the conceptual change model during learning provides an avenue for considering the adequacy of the alternative explanations available for ant natural or biological phenomenon. It also promotes use and assessment of evidence that supports any scientific claims (Roth, Anderson & Smith, 1987). Learners are able to understand the fact that scientific knowledge is developed through research directed by theories, and that through continued research scientific knowledge passes through continuous and sometimes tortuous process of validation or refutation.

**Conceptual Change Studies**

Several science education researchers have described learning science as a complex process resulting from conceptual restructuring (Audet & Abegg 1966; Gabel, 1994; Lave, 1991; Resnick, 1978; Stewart & Hafner, 1991). In a study investigating students' understanding of genetics using a computer

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simulation program, Audet and Abegg (1996) reported that students' knowledge of genetics could be gauged via its explication subsequent to the restructuring of an existing conceptions or knowledge of genetics. Audet and Abegg (1996) found that as novices progressed through a problem set they used higher-level cognitive operations more frequently than they originally did. From these findings the authors deduced that if effective reasoning skills were manifestations of understanding, then a hierarchical arrangement of problem solving styles exists. The type of questions progressive learners ask and the "question language" students use are indicators of conceptual change. These researchers have suggested exploration of students' knowledge explication as a means of probing students' understanding of scientific concepts.

Resnick (1978) and Vygotsky (1987) explained that in addition to individual processes, learning is a result of the social interactions among learners. Lave (1991), drawing on the work of these two authors, stated that cognitive change is the result of a combination of complex processes that go beyond what can be explained by the Piagetian developmental learning theory. Lave (1991) has described learning as the internalization of the concepts, values, and modes of thought initially practiced in social interactions.

Stewart and Hafner (1991) described problem solving strategies as "model-elaboration and model-revising as students develop better conceptual insights, and make links between the old and new models to produce a larger conceptual framework" (p.113). A plethora of misconceptions terminology that have been used to describe students' misconceptions are shown in Table 1.
In the present study the researcher has decided to refer to students' explanations that deviated from universally accepted scientific explanations as misconceptions or prescientific conceptions. The researcher’s choice of the misconceptions or prescientific terminology is supported by the work of Driver (1981) and the conceptual change theory (Posner, Strike, Hewson & Gertzog, 1982). Her use of the prescientific terminology specifically addresses students’ explanations that differ from scientifically-accepted ones and not the scientific methods used to derive knowledge of the phenomenon being explained.

Some science education researchers have argued that students may use prescientific explanations as analogical models of thinking and stepping stones in the development of more acceptable scientific explanations. However, the analogical model of learning has been proved to become a hinderance to
incremental conceptual restructuring when it comes to learning biological evolution (Hafner, 1991; Hafner and Stewart, 1992; Cummins et al., 1992). In fact, Moore (1983) and Demastes (1994) found that conceptual leaps are rare during the learning of comparative anatomy and evolutionary biology concepts.

Scientifically acceptable biological knowledge must, therefore, be built on correct fundamental knowledge of evolutionary concepts if meaningful understanding of concepts related to the origin of life and the subsequent biodiversity is to be developed based on scientifically correct precursor knowledge. Students must restructure their existing conflicting prescientific conceptions, develop, and be willing to utilize new scientifically acceptable conceptions in order to develop scientific and biological literacy (BSCS, 1993; Moore, 1983; Roach, 1994).

The researcher in this study prefers to use prescientific conceptions instead of the "misconceptions" terminology because it represents her view that conceptual change is achievable if learners are willing to rationally assess evidence which supports scientific claims they are presented with. Driver and Easely (1978) described identification of students' reasoning perspectives and of learning difficulties within the field of study as a good means of identifying conceptual problems among students.

Studies by Bishop and Anderson (1990), Cummins (1992), Demastes (1994), Tämir and Zohar (1991), Green (1990), Lawson and Weser (1990) on students' understanding of evolutionary concepts, biological phenomena and processes associated with life, have shown that students' prescientific
explanations are diagnostic of much deeper problems in the students’ conceptual frameworks about the nature of biological processes than was originally envisaged by biology educators. Good et al. (1992) have suggested that conceptual change studies involving an investigation of students’ conceptions of the nature of biological and evolutionary processes should include an examination of the nonscientific terminology and explanations used by students. This, in part, is due to the fact that prescientific conceptions in students’ explanations of biological phenomena may not simply be “artifacts of communication”, but rather, indications of a much deeper problem in students’ understanding of the nature of science.

**Nature of Science Research**

Findings from studies on the nature of science have increasing shown that an adequate understanding of the nature of science and of science as a way of knowing are essential goals of science education (AAAS, 1993; NRC, 1996, Rutherford & Alhgren, 1990). Understanding science as a way of knowing plays an important role in the development of scientific literacy (Moore, 1993). The AAAS (Rutherford & Alhgren, 1990) has outlined the properties of the nature of science under three major categories, namely, the scientific world view, scientific inquiry, and the scientific enterprise.

Under these categories science is described as a means of understanding the world through the consistent patterns comprehensible by careful, systematic study. Understanding the nature of science includes the understanding that core scientific knowledge has remained stable even though
new scientific ideas are subject to change. In also includes understanding science's demand for evidence, and its inability to provide answers to supernatural or other events outside the realms of nature. Latour (1987) describes science as fundamental knowledge with a stable but tentative nature. She also describes science as a dynamic type of knowledge in which scientists are constantly seeking an understanding of both what is known and what is not yet known about nature.

The stable core knowledge of science is in the form of laws, principles, and theories. For instance, the laws of energy conservation, motion, and the theory of evolution by natural selection are unlikely to change in their entirety in spite of new scientific discoveries or use of sophisticated instrumentation in scientific research. Such research only allows for confirmation or modifications of current scientific ideas in areas where data are still incomplete thus allowing for resolutions of current conflicting conceptions.

It is recommended in the various educational reform documents (AAAS, 1989, 1993; BSCS, 1993; NRC, 1996; Rutherford & Alhgren, 1990) that students should be taught that explanations based on myths, personal beliefs, religious values, mystical inspiration, superstitions, or authority even though seen as personally or socially acceptable can be completely outside the realm of science. The AAAS (1993) recommends that "students must know or at least be able to follow the science involved and grasp the main features of the prevailing view of science" (p.238). Understanding the historical developments in science becomes an important aspect of understanding the nature of science.
History and Nature of Science

Adequate understanding of the nature of science is described as best accomplished through an understanding of the history of science. Matthews (1994) describes a major role of the history of science as a means of reinforcing the understanding of the nature of science when basic questions such as "what do we know and how do we know it?" are asked by learners. These questions allow learners to question the methods of knowledge acquisition as well as knowledge production. Knowledge of the history of science, therefore, enhances and promotes healthy questioning. Questioning allows students to build concrete scientific knowledge.

Matthews (1994) describes another major role of the history of science as a means of contributing to a clearer appraisal of the many contemporary educational debates that engage science teachers and curriculum planners. Evolution education is an area in which such debates have been abundant. Learning is described as more challenging when there is enhanced reasoning and use of critical thinking skills and when students are able to appreciate the connections between personal, ethical, cultural, and political concerns than in the absence of interactions (Matthews, 1994). Students are able to realize that the development of scientific knowledge is a theory-driven human undertaking. Matthews (1994) also describes the humanization of scientific concepts and principles as a means of encouraging students to realize the fact that developments in science have mostly been driven by a dissatisfaction with the theories used to explain natural phenomena.
Similarly, science education researchers and biology educators believe that adequate understanding of the historical developments that have taken place in the development of biological knowledge is essential for promoting students' understanding of the nature of biological knowledge (Barnett et al., 1983; Nelson, 1986; Scharmann & Harris, 1992). This understanding is believed to enhance students' ability to follow and critique the thinking of pioneer biologists such as Aristotle and Darwin and all the other biologists who succeeded them. Students are able to follow the underlying assumptions of biology as they learn the subject more meaningfully. Understanding the history of science allows students to realize the universal and counter-intuitive nature of scientific knowledge.

Wolpert (1992) in *The Unnatural Nature of Science* describes the counter-intuitive nature of science in the following statement: "In fact, both the ideas that science generates and the way in which science is carried out are entirely counter-intuitive and against common sense" (p.1). Novak (1977) describes understanding the history of science as a means of contributing to a fuller understanding of the subject matter and helping students overcome the 'sea of meaninglessness' students have when concepts are memorized without knowing what they mean. This is in concert with the position of many science educators regarding students' depth of knowledge (Gabel, 1994). Wandersee (1985) and Wandersee and Roach (1998) identify the history of science as one of the potentially useful ways of promoting conceptual change in science education.
Studies on Students' Conceptions Related to the Nature of Science

An early most extensive study to assess students' conceptions of the nature of science was a nationwide qualitative study involving a sample of 35,000 students responding to the question "What do you think about science and scientists? (Mead & Metraux, 1957). Students who participated in the study were selected randomly from different age groups, gender, geographical locations and socioeconomic status all over the United States. Findings from this study revealed that students lacked proper attitudes towards science and did not understand the nature of science.

Klopfer and Cooley (1961) developed and used the Test on Understanding Science (TOUS), a paper-and-pencil assessment instrument of students' conceptions of the nature of science, and reported that most high school students had inadequate understanding of the nature of the science, the scientific enterprise, and the work of scientists. Using the TOUS, Miller (1963) reported similar findings of inadequacy in students' understanding of the nature of science. The above and similar research findings prompted the National Science Teachers Association to make a national call which fueled a proliferation of nature of science research on improved curriculum and instructional strategies that promote students' understanding of the nature of science.

Mackay (1971), in a comprehensive study involving 1,203 Australian secondary students, used the TOUS. His study revealed that students had insufficient knowledge of the role of creativity in science, function of scientific
models, roles of theories, and a distinction between hypotheses, laws, and theories. These students also lacked adequate knowledge of the scientific method, what constitutes a scientific explanation, and the relationship and interdependence among the different branches of science. Similar findings were reported by Korth (1969), Broadhurst (1970), Aikenhead (1973), and Bady (1979).

Rubba (1977) developed the Nature of Scientific Knowledge Scale (NSKS) to assess students' understanding of the nature of science. Using the NSKS Rubba and Anderson (1978) found that 30% of the high school students surveyed believed that scientific research reveals "incontrovertible and necessary absolute truth", and that scientific theories with constant testing and conformation eventually matured into laws. Horner and Rubba (1979) characterized students' prescientific conceptions about the nature of science were characterized by as "myths of absolute truths" and "laws-are-mature-theories fable".

Meichtry (1992) used a Modified Nature of Scientific Knowledge Scale (MNSKS) to investigate high school students' understanding of the nature of science. She examined students' understanding of the creative, developmental, testable, and unified dimensions of the nature of science and suggested explicit representation of all aspects of the nature of science in the science content taught in any study investigating students' understanding of the nature of science. She suggested that the science content students are learning should be directly related to various dimensions of the nature of science.
Lederman (1992) reviewed studies on students' and teachers' conceptions of the nature of science. He suggested that the tentative nature of science should be communicated to students, and included in all science curricula attempting to change students' conceptions about the nature of scientific knowledge. In Lederman's (1992) review, it is notable that over 40 studies have been conducted on middle and high school students' conceptions of the nature of science in the last two decades.

However, it is obvious that very few studies have been conducted at the college level. Moreover, for biological sciences most of the studies have been restricted to identifying students prescientific conceptions related to specific concepts. Little investigation of how such prescientific conceptions influence students' "grand schema" of the nature of biological knowledge has been done. Furthermore, the available studies in biology education do not show how students make connections among the various immediate physiological or functional processes, be it genetic, physiological or biochemical processes, and the ultimate processes that influence the long-term survival of populations of organisms.

Based on the suggestions made in the available science education literature (Barnett et al., 1983; Good et al, 1992; Smith et al., 1995; NAS, 1998), the present study investigates students' conceptions, explanations, and ability to make connections among biological concepts related to general biology, evolutionary processes, homologous and analogous anatomical features as observable products of evolutionary processes. The study also examines how
students' "grand" conceptual frameworks related to these biological phenomena relate to their understanding of similarities and differences among living organisms, biological classification, and indirectly provides insight into college students' levels of biological literacy.

Teaching about Nature of Science and Evolution

The importance of evolution for understanding the nature of science and the nature of biological knowledge is increasingly being acknowledged in science education literature (AAAS, 1990, 1993, NRC, 1996, BSCS, 1993, NAS, 1998). In spite of this, understanding of evolution as the cornerstone of the nature of biological knowledge remains minimal. The National Academy of Sciences in Teaching about Evolution and the Nature of Science (NAS, 1998), describes teaching evolution as having two major functions. The first function is to reinforce students' understanding of the nature of science and science as a way of knowing. This is because it promotes students' understanding and explanations about the natural world as based on empirical evidence and confirmable data. The second is to differentiate science from other forms of human endeavor or understanding because "many people see evolution as conflicting with widely held beliefs about life, hence the teaching of evolution offers a superb opportunity to illuminate the nature of science" (p.4).

The importance of understanding evolution as a means of understanding the history and nature of biological knowledge is emphasized in various education reform documents (AAAS, 1989, 1993; BSCS, 1993; NRC, 1996; Rutherford & Ahlgren, 1990) and discussed by numerous science and biology
educators (Cummins & Remsen, 1992; Good et al., 1992; Moore, 1984; Scharmann, 1993; Scharmann & Harris, 1992; Tamir & Zohar, 1991; Wandersee, 1985). Moore (1993) described understanding evolution as providing the historical basis of biological knowledge, and as a means of promoting students' learning of biology in a meaningful way. The American Society of Zoologists (Moore, 1984) recommended that college zoology students should be taught to understand "biological sciences as a way of knowing" (p. 470).

Reports by Birx (1991) and studies by Barnett et al. (1983), Nelson (1986), and Scharmann (1993) suggest that adequate understanding of the development of the theory of evolution by natural selection is necessary for understanding the conceptual developments that have taken place in the development of biological knowledge. Understanding the historical parallels between students' experiences in the classrooms and 19th-century scientists' experiences following Darwin's publication of On the Origin of Species (Darwin, 1859) may help students to understand the "conceptual revolution" required for understanding the nature of biological knowledge (Birx, 1991).

Similarly, Smith et al. (1995) lamented that large numbers of educated people, including scientists, continue to reject the theory of evolution. Demastes, Trowbridge, and Cummins (1992) report that many students in biology classrooms and members of the public continue to view the biological world from a pre-Darwinian perspective. Eve and Dunn (1990) found that many biology teachers have serious questions when it comes to evolution. 

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implications of the continued rejection and lack of understanding of the theory of evolution by teachers and their students are far-reaching in terms of scientific and biological literacy. Biology teachers who have difficulty accepting the theory of evolution by natural selection are unable to provide scientific explanations for the evolutionary and related biological concepts they are discussing with their students.

Such teachers and students with conflicting prescientific conceptions about the origin of life may also find it difficult to make conceptual connections among the functional (physiological, biochemical) and structural (anatomical) similarities and differences observed among the living organisms. In terms of biological literacy, such students are more likely to continue holding prescientific beliefs about life and other biological processes during their adult life. They will also find it difficult to attain multidimensional biological literacy. Rudolf and Stewart (1998) describe the continued rejection of the theory of evolution as a major problem for the public's perception of science as a whole.

Adequate understanding of the nature of biological knowledge, therefore, requires meaningful understanding of the nature of science, biological and evolutionary processes, and the consequences of such processes on living organisms. Specific terminologies used to describe students' prescientific conceptions and explanations related to their understanding of biological processes are summarized in Table 2.
<table>
<thead>
<tr>
<th>Terminology</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reductionism</td>
<td>All systems in nature are understandable by reducing them to the smallest components, and higher levels of every system can be explained using the smallest components.</td>
</tr>
<tr>
<td>2. Constitutive nonreductionism</td>
<td>Living and nonliving things are not composed of similar materials and/or the materials are not subject to the same physical laws.</td>
</tr>
<tr>
<td>3. Nonemergentism</td>
<td>The whole organism is no greater than the sum of its parts. Or the various levels of organization have no major influence on characteristics of the whole organism.</td>
</tr>
<tr>
<td>4. Special creation</td>
<td>All living things are created by an act of a supreme deity (God).</td>
</tr>
<tr>
<td>5. Typology</td>
<td>Evolution is directed toward perfection of every kind of organism in order to preserve each kind.</td>
</tr>
<tr>
<td>6. Teleology</td>
<td>Events in nature are directed by a predetermined purpose.</td>
</tr>
<tr>
<td>7. Orthogenesis</td>
<td>Evolution is a spontaneous change producing new species or mass extinctions of old species. Selection is ignored.</td>
</tr>
<tr>
<td>8. Vitalism</td>
<td>A mystic, nonmeasurable motive force exists in living organisms.</td>
</tr>
<tr>
<td>9. Lamarkianism</td>
<td>Traits acquired through need or environmental influence during an organisms's lifetime are inheritable.</td>
</tr>
<tr>
<td>10. Anthropomorphism</td>
<td>All living organisms possess or display a purposeful or human-like behavior.</td>
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</tbody>
</table>
Students are bombarded everyday with activities, newsletters, magazines, movies, and various forms of conflicting nonscientific information which may be inhibitory to their conceptual understanding the nature of biological knowledge. Birx (1991) describes conceptual understanding of evolutionary processes as a "conceptual revolution", because it requires logical understanding of the various forms of evidence of life that surrounds us in nature. Lawson and Weser's (1990) study show that students with prescientific conceptions about biological processes are more likely to accept nonscientific beliefs about life than those who do not.

Greene's (1990) study suggests that relationships exist among students' prescientific conceptions which do not conform to current scientific thought. Barnett et al.'s (1983) study suggest that students who do not understand the theory of evolution and those who accept it uncritically may not understand the nature of science. Using conceptual change teaching strategies, biology teachers as well as students can gradually begin to see that the above prescientific modes of explanations do not enhance their understanding of the nature of biological knowledge. Dissatisfaction with prescientific explanations for living organisms help both teachers and students with difficulties originating from long-held belief systems to explore the plausibility of scientific explanations provided by scientific theories. Understanding of scientific explanations of biological processes determines one's understanding of the nature of biological knowledge.
Nature of Biological Knowledge

In the BSCS (1993) report, Developing Biological Literacy which was designed for the improvement of secondary and post-secondary biology curricula understanding, the nature of biological knowledge is described as an understanding of the characteristics of scientific knowledge, values of science, methods and processes of scientific inquiry, and the unifying principles and concepts of biology. Understanding these characteristics of scientific knowledge, methods and processes of scientific inquiry, and the unifying principles of biological knowledge are identified as important attributes for understanding the nature of biological knowledge. The following characteristics of the nature of science research are recommended as necessary for adequate understanding of the nature of biological knowledge (p.16):

1. Biological knowledge is tentative and subject to change.

2. Biological knowledge is universal and public. Therefore, all knowledge claims must be reported or made known to the public.

3. Biological knowledge is empirical. Observation of nature and experimentation with nature are the basis of knowledge. Knowledge validation or refutation should be based on the nature without appeal to supernatural explanations.

4. Biological knowledge is replicable. Scientists working in different locations at different times should be able to repeat another biologist's observations and experiments and derive the same evidence.

5. Biological knowledge is historic. Knowledge builds on and revises the
accumulated corpus of understanding. Knowledge from the past and present are the basis for future knowledge. Current knowledge should be understood in its social, technological, and political context.

Subsequently, biological knowledge is based on evidence. Data verification and logical reasoning about of biological phenomena should, therefore, be built on sound scientific knowledge. All biological concepts necessary for understanding the nature of biological knowledge have been organized by the BSCS (1993) into six the major biological principles shown in Table 3 below.

Table 3: Unifying Biological Principles

<table>
<thead>
<tr>
<th>Principle (Concept)</th>
<th>Construct (Explanation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Evolution: Patterns and products of change.</td>
<td>Living systems change through time.</td>
</tr>
<tr>
<td>2.Interaction and interdependence</td>
<td>Living systems interact with their environment and are interdependent with other systems.</td>
</tr>
<tr>
<td>3.Genetic continuity and reproduction.</td>
<td>Through reproduction living systems are related to other generations by genetic material passed onto their offsprings.</td>
</tr>
<tr>
<td>4.Growth, development, and differentiation</td>
<td>Living systems grow, develop, and differentiate during their lifetimes based on a genetic plan.</td>
</tr>
<tr>
<td>5.Energy, matter, and organization</td>
<td>Matter and energy are required by living systems in order to maintain a highly organized and complex organization.</td>
</tr>
<tr>
<td>6.Maintenance of a dynamic equilibrium</td>
<td>Through various regulatory mechanisms and behavior living systems maintain a relatively stable internal environment.</td>
</tr>
</tbody>
</table>

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The six biological principles above are listed in their order of importance for building a conceptual understanding of the nature of biological knowledge. The BSCS (1993) emphasized the evolutionary basis of biological knowledge by placing adequate understanding of the theory of evolution at the top of the list. The importance of evolution in biological knowledge is emphasized analogically in the following statement: "One can think of the unifying principles as branches on a tree that has evolution as its trunk and the "facts" of biology as its leaves" (BSCS, 1993, p. 20).

Mayr (1977) has described understanding the nature of biological knowledge as dependent on understanding the role of "chance, pluralism, history, and uniqueness" (p.56). He describes understanding the theory of evolution as a central prerequisite for understanding the nature of biological knowledge. Students' conceptions of the role of chance, pluralism, history, and uniqueness of organisms are believed to depend on their understanding of the theory of evolution and how it unifies all the other principles of biological knowledge shown in table 3 on page 33 above.

Mayr (1997) has suggested that an understanding of the following five basic steps may be prerequisites for understanding the processes involved in long-term development of biological literacy. He describes observation of an undisturbed nature as the most important first step in understanding the living world. Secondly, formulating "how?" and "why?" questions, and constructing a tentative conjecture or working hypothesis are described as the next important steps. Thirdly, the validation of the conjecture, and development of a complete
biological explanations which provide proximate (functional) as well as ultimate (evolutionary) explanations of biological phenomena. Moore (1984) has described students' understanding of the scientific methods of inquiry used in biological as essential because biological knowledge has a dual nature. On the one hand, biological knowledge is a process of knowing. On the other hand, it is a product of knowing. Understanding of evolutionary mechanism and processes, structural or behavioral features that are products of the evolutionary process are described as fundamental for making connections among the various biological concepts.

Cummins & Remsen (1992) have described the nature of biological knowledge as best understood through understanding the history of science. Using the history and philosophy of science, these authors confer with Mayr (1988) and suggest that complete causal explanations of biological phenomena should include both proximate and ultimate causation. The latter level of causation is based on the evolutionary history of biological phenomenon in question.

**Evolutionary Basis of the Nature of Biological Knowledge**

natural selection as the unifying theme for organizing the biology curriculum and instruction. Evolution is also described as an interdisciplinary concept whose understanding is necessary for understanding the concept of change in all natural systems. The National Research Council in *Fulfilling the Promise* (1990) describes the roots of students' misconceptions about the nature of biological knowledge as being grounded in and traceable to elementary, middle and high school science, or college biology curricula in which biological evolution is lacking. In the same NRC (1990) report it is recommended that:

"Evolution should be taught as a natural process, as a process that is as fundamental and important in the living world as any basic concept of physics one can name. The evidence that supports evolution - the physical measurement of the age of the earth, the fossil record, patterns of similarity in body plans, the record left in primary structures of nucleic acids and proteins should all be examined, and students led to how such disparate knowledge knits together to form an elegant and coherent whole" (p.23).

The National Research Council in the *National Science Education Standards* outlines the following concepts as necessary for understanding the nature of biological knowledge (NRC, 1996, p.185):

1. Species evolve over time.
2. The great diversity of organisms is the result of more than 3.5 billion years of evolution.
3. Natural selection and its evolutionary consequences provide the scientific explanation for the fossil record of the ancient life forms as well as the striking molecular similarities observed among diverse species of living things.
4. The millions of different species of plants, animals and microorganisms that live on earth today are related through descent from a common ancestry.

5. Biological classifications are based on the evolutionary relationships of the organisms.

Mayr (1988) has explained that an understanding of the nature of biological knowledge is incomplete without an understanding of the evolutionary history of biology because adequate understanding of the nature of biological knowledge is embedded in knowledge of evolutionary biology. Students' perceptions, beliefs or viewpoints about biological phenomena may be related to their inability to recognize the multilayered nature of biological knowledge.

Mayr (1997) describes an adequate understanding of the nature of biological knowledge as understanding the differences between the physical and biological sciences or proximate and ultimate levels of causation. This understanding allows students to think critically and evaluate the scientific methods and kind of questions used by scientists to understand biological phenomena as opposed to methods used in the physical sciences.

Biological sciences deal with questions related to life processes, however, biologists require knowledge of the physical sciences to answer proximate physiological processes in living organisms. Cummins and Remsen (1992) found that most students' misconceptions of biological evolution are associated with their inability to distinguish between the proximate and ultimate
kinds of causation. Lack of understanding of ultimate causation is believed to transfer from a lack of understanding of the nature of evolutionary change. This may also transfer into a general lack of understanding of the nature of biological knowledge. Table 4 provides a summary of the comparisons between biological and physical sciences.

Table 4: Comparisons of Biological and Physical Sciences

<table>
<thead>
<tr>
<th>Biological Sciences</th>
<th>Physical Sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Research usually has an observational, descriptive, comparative, or experimental nature.</td>
<td>Research tends to be experimental in nature.</td>
</tr>
<tr>
<td>2. Incorporate genetic basis with historical roots of the process under study.</td>
<td>No genetic basis involved, and with the exception of astronomy most problems in the physical sciences can be understood independently of their history.</td>
</tr>
<tr>
<td>3. Require an understanding of nonreductionism and emergence in structured living systems.</td>
<td>Require an integration of essentialism and reductionism in non-living systems.</td>
</tr>
<tr>
<td>4. Deal with both organismal and non-organismal science.</td>
<td>Mostly deal with physical or non-organismal science.</td>
</tr>
<tr>
<td>5. Deals with both proximate and ultimate causation.</td>
<td>Deal with mostly proximal causation.</td>
</tr>
<tr>
<td>6. Provides different answers to “how” and “why” questions.</td>
<td>Provides same answers to “how” and “why” questions.</td>
</tr>
</tbody>
</table>

Cummins' (1992) study showed that students who do not use multi-layered reasoning have difficulty differentiating biological from physical phenomena. Such students lacked the knowledge of observational studies

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characterized by use of descriptive, comparative and sometimes experimental methods which are typical of research in the biological sciences. They understood biology as similar to the physical sciences in all aspects, particularly, in terms of the emphasis placed on experimental research.

The emergent and nonreductionist nature, and ultimate levels of causation in living systems lead to different answers when reasoning about living and physical systems even though biologists require knowledge of the physical sciences to understand living systems at the molecular level. Physiological or functional characteristics of living organisms are essentially similar to physical properties of physical objects. However, understanding and interpretation of anatomical or structural similarities and differences among organisms require understanding evolution in addition to proximate levels of causation.

Walker and Liem (1994) describe understanding of the similarities and differences in structure, function, and evolutionary history (phylogeny) of living organisms as the basis for understanding biodiversity. They describe understanding biodiversity in terms of understanding the origin as well as microevolutionary and macroevolutionary trends of biological processes. Students must, therefore, develop scientifically-acceptable conceptions about biological processes and the nature of change in living organisms.

Studies on Students' Conceptions of Evolution and Biological Processes

Adequate understanding of the mechanism and processes of biological evolution is believed to provide a foundation for scientific understanding of the

Students who do not fully understand the nature of biological knowledge may employ nonscientific explanations such as typological (Homberger, 1988), Lamarckian (Bishop & Anderson, 1990), anthropomorphic (Tamir & Zohar, 1991), or teleological explanations (Cummins, 1992) to describe biological phenomena. These students may also provide creationist, constitutive nonreductionist, nonemergentist, vitalist and orthogenetic explanations about the changes that occur in living organisms.

Tamir and Zohar's (1991) investigation of high school students' modes of reasoning about living organisms shows that most students use teleological explanations when describing biological processes related to animal species. Their study also show that such students use anthropomorphic explanations when describing biological processes as well as physical processes which occur in non-living objects. Cummins' (1992) study showed similar animistic explanations among high school and college students. Such animistic conceptions students among students are a form of vitalism. Both Tamir and Zohar's (1990) and Cummins's (1992) studies imply that students believe in the
presence of a vital force in living as well as non-living things. Barnett et al. (1983) assessed three groups of college zoology students using questions derived from the philosophy of biology and related to evolutionary theory. These researchers found very little evidence of critical understanding of the concept of natural selection among students. Two-thirds of the students accepted natural selection uncritically as a dogma. Almost all the students had reductionist and nonemergentist perceptions about biological systems. Most students believed that all biological processes are reducible to physical entities. Barnett et al.'s (1983) study suggest that students did not understand the emergent nature or the hierarchical organization of biological systems.

Scharmann's (1993) study shows that adequate understanding of the history and philosophy of science are good means of providing students with a better understanding of the nature of science and of biology. Both instructors and students who follow the chronological order of the kinds of biological explanations that had been developed and validated over the years are in a better position to develop scientific understanding of biological knowledge. He also found that understanding the history of science, particularly, of biological knowledge reduced anxiety among both instructors and students when they were discussing organic evolution.

Scharmann and Harris (1992) reported that adequate understanding of the history and nature of science promotes critical thinking and scientific reasoning among students as well as teachers. This is particularly true when peer-group discussions are used in biology classrooms. Nelson's (1989) study
with high school biology teachers shows that teachers understand and apply the theory of evolution more clearly in their teaching and explanations of biological phenomena when they have an adequate understanding of the nature of science.

Jensen and Finley's (1996) study showed that some reduction in students' pre-scientific conceptions related to evolutionary concepts occurred when a historically-rich curriculum was used in combination with paired problem solving during instruction. These researchers found that the number of students who correctly identified inconsistent, nonscientific explanations about living organisms also increased. Jensen and Finley's (1996) study, however, showed that the technique of introducing students to historical precursors of Darwin's evolutionary theory may be limited in its effectiveness to promote conceptual change. Overemphasis of pre-Darwinian explanations may be mistaken by students as scientifically acceptable and inhibit conceptual understanding of the evolutionary process.

Lawson and Weser (1990) examined 944 university students to determine the extent to which these students held nonscientific beliefs about life. They found that students held many prescientific beliefs including special creation, orthogenesis, constitutive nonreductionism, vitalism, teleology, and nonemergentism. Students with prescientific conceptions about life were found to be mainly intuitive reasoners. Intuitive reasoners had difficulty changing their explanations from prescientific beliefs to scientific explanations even when presented with scientific evidence. Reflective reasoners who evaluated the
evidence they were presented with tended to provide more scientific explanations about biological phenomena. Lawson and Weser's (1990) findings present a great challenge to instructors on the type of reasoning instructors themselves use when explaining evolutionary processes. Demastes and Wandersee (1992) reported that broad-scale mastery of evolutionary concepts may be elusive. They suggested use of relevant rather than abstract concepts as a better means of promoting biological literacy than so far considered.

Bishop and Anderson (1990) showed that students who perform well in the traditional biology course work often fail to grasp the most fundamental evolutionary concepts. They identified three areas in which students' conceptions of natural selection differed radically from those of biologists. Many students provided a Lamarckian explanation of natural selection. They described natural selection as a process by which individual organisms change in response to changes in the environment. According to these students, the environment rather than the organisms' genetic make-up, exerted its influence through need, use, or disuse to cause variation.

Secondly, students were unable to distinguish the origin of a trait from selection on that trait. Finally, students viewed change as taking place in the traits and not as an increase or decrease in the numbers of individuals in the population with such traits. Smith, Blakeslee and Anderson (1993) reported findings that were similar to those Bishop and Anderson (1990). The lack of understanding of the mechanism and processes of natural selection is a major
hinderance in students' construction of scientifically-acceptable explanations of the evolutionary process. Evolution is seen as change in traits in a homogenous population. Variation in genetic material and the influence of selection on genetic variation are not recognized by students. The homogenous population viewpoint suggests presence of essentialistic or typological conceptions among students. These students believe that populations of living organisms are made of same "kinds" of organisms and that any change that occurs is predetermined to preserve the "kind" of organisms in question. Literature on the historical developments in biological knowledge (Matthen & Linsky, 1988, Ruse, 1988; Birx, 1991) reveal that essentialistic or typological reasoning are rooted in special creationism.

Smith, Blakeslee and Anderson's (1993) study suggest that inhibiting and conflicting ideas students hold cab be overcome by use of conceptual change teaching strategies. Jime'nez (1992) investigated the conditions necessary to promote conceptual change in evolution within a secondary school science classroom. She compared instruction which emphasized students' conceptions with instruction which linked students with Darwinian and Lamarckian interpretations.

She found that many of the students' explanations about evolution are typically Lamarckian. No difference was observed in students' test results on declarative knowledge and questions requiring application of the theory of evolution, particularly with instruction which emphasized students' existing conception. Students performed better under instruction which differentiated
between historical Darwinian and Lamarckian interpretations. Jimenez's (1992) study shows that explicit discussions allow students to see deficiencies in their own conceptions. Such discussions may augment conceptual change. Brumby (1984) explored medical students' conceptions related to natural selection using written questions and structural interviews. He found that students held Lamarckian view of evolution that evolutionary change occurred because of need. Others students saw change as caused by the environment, with such change gradually unfolding in the offspring. Only 18% of the medical biology students could correctly apply natural selection as responsible for evolutionary change.

Greene (1990) investigated the logic of misunderstanding of natural selection among 322 university sophomores and found that students have two major prescientific assumptions. Students' first prescientific assumptions are that genetic variation play no role in evolutionary processes. Their second prescientific assumptions are that when nature changes it does not change at random. Students believe that such changes are predetermined by need, use, disuse or environmental influence. Students who completely ignore the role of selection provided teleological and orthogenetic explanations.

In the same study, Greene (1990) found that students confused the selection process with the function of the traits that generate change. Students who provided Lamarckian explanations argued that all the characteristics acquired during a life time are passed on to the subsequent generations.
Greene's (1990) study also showed that 43% of the preservice elementary education majors who participated in his study had only a functional understanding of natural selection, and 17% used Lamarckian explanations. Poor conceptions about the role of chance and random selection confounded students' misconceptions about natural selection. Inherent students' beliefs contradictory to scientific conceptions and explanations have also been found to be partly responsible for the difficulty students have in modifying their existing conceptual frameworks (Wandersee et al., 1984).

Clough and Wood-Robinson (1985a) interviewed 84 students with the aim of identifying common belief patterns they had about evolution and inheritance. These researchers found that first year students had a coherent conception of inheritance but many held that over time the phenotypic changes acquired by the organisms due to the interactions with the environment became inheritable. Many students excluded genetic changes from their explanations. In the same study by Clough and Wood-Robinson (1985b), many of the students explained adaptation in teleological and anthropomorphic terms. Many students did not connect the adaptive processes and features in organisms to evolutionary change. Students confused natural selection in populations with adaptive physiological changes observed in individuals.

Settlage (1994) found that teleological and Lamarckian explanations accounted for over half of students' explanations at pretest. The frequency of these types of explanations dropped to less than 20% at posttest on questions related to evolution. Most of the students who provided Lamarckian reasoning
by attributing evolution of specific traits or features to individual need, extended use, and disuse of some part of the body on the pretest shifted on the posttest to explanations that describe the role of variation in a population to the evolutionary process.

Grant (1991) found that students' interpretation of the term "fitness" misleads many students into thinking that natural selection is always beneficial to the organisms. These students also associated mutations with negative effects on the organisms involved. They also confused proximate with ultimate causation, and mutations with natural selection. Cummins (1992) found that college biology students employ mostly the proximate causation and not much of ultimate causation in their explanations of biological phenomena. She suggested that the overemphasis of proximate physiological processes throughout students' high school and college programs may be partly responsible for students' lack of knowledge about ultimate evolutionary processes.

Keown (1988) found that mechanistic and reductionist reasoning models are partly due to the way science is taught. He reported that many natural science curricula may not be preparing students for understanding science and biology as a process. Keown (1988) proposed that instructors should concentrate on the major underlying biological concepts such as natural selection, geologic time, and genetic variation among organisms of different species. Hafner (1991) reported that understanding evolutionary phenomena require students to develop critical thinking and reasoning skills.
Hafner and Hafner (1992) reported that the widespread scientific illiteracy in the U.S. in the area of evolutionary biology suggests that the methods of teaching employed are falling short of the intended goals. Students have been found to have many inherent conflicting conceptions that inhibit development of conceptual understanding. Demastes, Abrams and Cummins (1996a) studied second, fifth, eighth and twelfth graders as recommended by Project 2061 (AAAS, 1993). They found that an incremental pattern of conceptual change occurs among grade students.

German, Aram and Burke (1996) studied 364 seventh grade students by using process skills as a measure of the means of facilitating students' success in designing experiments and formulating hypotheses. These educational researchers found an incremental development of process skills among students during learning. Studies by Jeffry and Roach (1994) revealed a considerable absence of evolutionary precursor concepts in elementary and middle schools textbooks. They concluded that this absence is partly responsible for students' lack of understanding of the nature of science. Jeffry and Roach (1994) explained that the acute absence of evolutionary concepts in lower-middle and high school textbooks is responsible for the numerous misconceptions students have when explaining biological phenomena at high school and college levels.

The above mentioned studies show that students who employ prescientific explanations about biological evolution and other biological phenomena have inadequate prior knowledge of the nature of science as they
passed through grades K-12 science. It also shows that there is transfer of this lack of understanding of the nature of science as inability to understand the nature of living organisms during biology courses.

Moore (1984) reiterated the position of the American Society of Zoologists by emphasizing that undergraduate biology and zoology students need to understand the critical importance of the nature of science and the theory of evolution as it relates to the understanding of concepts in all biological science disciplines including comparative anatomy. Kent (1992), and Walker and Liem (1994) identified understanding of the historical development of comparative anatomy, homologous, and analogous features shared by living organisms as very important in understanding biodiversity.

The American Association for the Advancement of Science through Project 2061 (AAAS, 1990, 1993) supported this position by describing the modern theory of evolution as a unifying principle for understanding the history of life on earth, relationships among living things, and the dependence of life on the physical environment (p.69). At the National Association of Biology Teachers' convention Dobzhansky (1937) stated:

"Nothing in biology makes sense except in the light of evolution".... "without the knowledge and understanding of the mechanism of evolution, all the biological sciences become a pile of facts with no meaningful picture as a whole" (p.125).

The NRC (1996) reiterated that evolution is "a major unifying idea that transcends disciplinary boundaries in and outside science, and as a powerful idea that should be used across all grade levels to guide biology instruction and
align the curriculum" (p.185). Similarly, the American Society of Zoologists recommended that all biology students should understand the role of evolution in explaining similarities and differences among living organisms.

**Homologous and Analogous Anatomical Features**

Homologous and analogous anatomical features are products of divergent and convergent evolutionary processes. Anatomical homology, by definition, is the presence of anatomical features or structures that are homologous in two or more species or taxa, in which the features can be traced back to a common precursor in the ancestral species or taxa.

**Homologous Anatomical Features**

Walker and Liem (1994) have described four types of anatomical homologous features, namely, evolutionary, structural, functional, and genetic homologous features. Genetic, evolutionary and structural homologies are closely related because organisms of similar evolutionary descent tend to have similar structural features. Secondly, the development of anatomical homologous features in sexually reproducing organisms are genetically determined in the organisms' primordial cells.

The genetic blueprint that is passed on to subsequent generations during evolution is evidenced by development of evolutionarily similar features in the offsprings. This phenomenon is explained by Meckel-Serr's law of developmental biology which states that: "phylogeny always recapitulates ontogeny" (Mayr, 1997, p.164). This law explains how embryos of sexually reproducing organisms develop by passing through phylogenetic stages similar
to those which their ancestors had evolved. Hansen (1981) explains that phylogeny recapitulates ontogeny because exchange of genetic material during sexual reproduction is a prerequisite to divergent evolutionary processes.

Divergent Evolutionary Model

As a first step in reconstructing the phylogenetic history of organisms, biologists compare anatomical features in organ systems among living organisms, and those of living organisms with extinct organisms to search for a relationship. Using evolutionary homology as comparative method used, the degree to which features in two or more species of an organism have diverged from features observed in their common intermediate ancestral species can be determined. Presence of homologous anatomical structures confirms evolutionary relationship between two or more taxonomic units (Kent & Walker, 1994; Homberger, 1988).

Topographical relationships in homologous features among two or more species are deduced by comparing the relative positions of the structural homologous features of contemporary species belonging to the same taxon (Hansen, 1981). A typical example of evolutionary homologs are the bones of the pectoral or pelvic girdle of a human, a horse, and a seal. The structural elements of these bones of the forelimbs or hind limbs in the three species are derived from the same embryonic precursors (Kent, 1992). Homologous features may also be derived through divergent and parallel evolutionary processes. Figure 2 and 3 show divergent and convergent evolutionary models in ancestral species A (modified from Walker and Liem, 1994).
Parallel Evolutionary Model

Parallel evolution occurs when structural features are derived in a closely related intermediate species of similar ancestry. Both homologous and homoplastic features may result from parallel evolutionary processes. Figure 3 shows a model of a parallel evolutionary process in which evolution homologous features A and A' and homoplastic features a and a' are derived from homologous features A in ancestral species A1 and A2. This model is modified from Walker and Liem (1994) and Hansen (1981).
Figure 3: Parallel Evolution of Homologous and Homoplastic Features

The best example of homoplastic features are provided by the wings of a bat and those of a weaver bird. Both of the wings are specialized forelimbs, but are homoplastic rather than homologous. The two types of wings evolved in independent taxa with the bat's mammalian wing being an enlarged, webbed hand, whereas the weaver bird’s avian wing is a fused radial and ulnar bones modified by muscle attachments and feathers for flight. For instance, if an ancestral species A3 had a feature A from which features a, a', a", and a"" in intermediate and contemporary species of organisms belonging to the same taxon have evolved by parallel evolution, then features in intermediate species are homologous to those in the ancestral species as shown in Figure 4.
Analogous Anatomical Features

Analogous anatomical features are found in two or more taxa or species, in which the features perform similar functions. Analogous anatomical features evolve in independent taxa or species from different precursor features in their intermediate ancestry through the process of convergent evolution. Convergent evolution is responsible for the development of analogous anatomical features among two or more independent taxa of organisms that live under the same or similar environment conditions. Such features are not traceable to a similar feature shared by intermediate species of the organisms involved. Analogous features evolve in independent species or taxa through convergence.
Convergent Evolutionary Model

Figure 5 below shows the model for convergent evolution. In this model analogous features a, a' and a" are derived from feature A in taxon A or species A. And features b, b', b" and b'" are derived from feature B in taxon or species B.

{<--------Convergence----------->}

<table>
<thead>
<tr>
<th>analogous features</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  a   a'  a'' b'' b' b</td>
</tr>
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</table>

Figure 5: Convergent Evolution of Analogous Features in Species A and B

A and B are two independent taxa which do not share an intermediate taxon or species in addition to being unable to interbreed. The only common characteristic they share is living in the same environment. Living in the same environment subjects both species to the same selective pressure. Analogous features a and b or a' and b', or a" and b" perform similar functions in the two taxa or species A and B. Examples of convergent evolution include the evolution of the gills of fish and the lungs of whales. The evolution of fish gill
and the whales's lungs from features that are dissimilar in terms of evolutionary precursors. The two features are also very different in structure or morphology, and yet they perform similar functions as a result of convergent evolution within a marine environment. Both features function in the two independent species for gaseous exchange.

Ashlock (1979) showed that understanding divergent, parallel and convergent evolutionary models enhance biologists understanding of classification. Mayr and Ashlock (1991) found that students' understanding of the structural similarities and differences observed among organisms of the same species are enhanced by their understanding of divergent and convergent evolutionary models. Understanding the divergent, parallel and convergent models of evolution may also allow students to make connections among the seemingly disparate knowledge of genetics, physiology, biochemistry or anatomy which together allow biologists to understand the characteristics of living organisms.

Organisms that share homologous structural anatomical features usually belong to same or related species and also share similar genetic materials from their intermediate ancestry. They are also reproductively compatible and produce viable offsprings through exchange of their genetic material. In this study, the extent to which college biology students' holistic conceptual understanding of divergent and convergent evolutionary models influence their understanding of speciation, biological classification, and similarities or differences among invertebrate and vertebrate species were examined during
student interviews. The study indirectly allowed for an examination of college students' understanding of speciation and processes responsible for biodiversity.

**Homology and Speciation**

Most contemporary biologists agree with Mayr (1982) that "after Darwin's book *On the Origin of Species* (1859) the only definition of homologous features that makes biological sense is: a feature (character or structure) in two or more taxa that can be traced back to (derived from) the same or corresponding feature in the presumptive common ancestor of these taxa" (p.232). Wiley (1981) defined homology by reinforcing scientists Mayr’s (1982) definition of homology, and explained that parallelism results from similar characters evolving by independent transformations from same ancestral character.

Streidter and Northcutt (1991) expanded further on Wiley's (1981) definition of homology and proposed a hierarchical concept of homology which permits biologists to ask new questions about how evolutionary changes at the various levels of biological organization are interrelated. With this definition, the level of organization he proposed that should be used to define homologous features is the species level.

**Definitions of a Species**

Most biologists today agree that a species is a population of organisms that is freely interbreeding and exchanging genes among themselves within a geographically isolated locality. Because of the importance of understanding evolution for understanding the species concept, which in turn is necessary for
understanding the nature of biological knowledge, students in this study were assessed for their understanding of the definition of a species, and how an understanding of evolution helps us to understand speciation. Several models have been proposed by various schools of biologists throughout history to explain the mechanisms of speciation.

Species Concepts

Proposed species concepts have included typological species concept, biological species concept, and the phylogenetic species concept. The biological species concept incorporates the evolutionary history and genetic make-up of the organisms, is by far the most universally accepted species concept. For sexually reproducing organisms, particularly vertebrate species, there is no question about the important role exchange played by exchange of genetic material in the continuity of the species involved. Evolution of subsequent generations from existing populations is a result of natural selection acting on the genetic traits present in varying proportions among members of those populations. Ecological modifications by the environment may create a geographical, vegetational or other extrinsic barriers that result in zones of contact where interbreeding can no longer occur.

Speciation Models

Various models of speciation, such as the allopatric, dichopatric, parapatric, peripatric and sympatric speciation have been proposed. In allopatric speciation new species are formed principally as a result of a major geographic isolation of parent generations. For instance, allopatric species
found on the various continental land masses isolated by geographical barriers. In dichopatric speciation new species are formed when parental species become divided by minor geographical, vegetational or other extrinsic barriers. In parapatric speciation progressive divergence of two populations that have contagious geographic ranges with no interbreeding in contact zone of two new species which are no longer interbreeding. In peripatric speciation the origin of new species is through the modification of peripherally isolated founder populations through a process called budding.

In sympatric speciation there is speciation without geographical isolation, perhaps by ecological specialization or acquisition of isolating mechanisms within a community of potentially interbreeding individuals at a given locality, also called a deme. Regardless of the type of speciation, it is generally agreed that no two organisms belonging to different species can produce fertile offsprings that are able to pass on their genes to future generations. Understanding the evolutionary mechanism and processes are, therefore, necessary for meaningful understanding of the origin of homologous anatomical features, models of divergent and convergent evolutionary processes and speciation. This understanding in essence is necessary for understanding how biological classification of organisms are generated.

**Homology and Biological Classification**

For students in the classrooms, this understanding is important for meaningful learning of hierarchical nomenclature of the classification system used in the biological sciences, beginning from the species to the phylum.
levels. Mayr (1997) described the classification system based on evolutionary biology as the best means of enhancing students' understanding of biodiversity. Ashlock (1979), in a study with college zoology students, found that students who employed evolutionary models for constructing phylogenetic trees understood taxonomy and biological classification better than those who did not. These students were in a better position to identify the organisms and construct their phylogenetic relations by answering the two basic questions: "what is what?" and "what evolved from what?" (p. 442).

The work of Ashlock showed that students' understanding of biological classification is greatly enhanced when students are allowed to observe, work with various species of organisms, and identify the homologous features shared among species of organisms. His work also showed that Peer discussions among the students enabled students to recognize the deficiencies in a Linnaeus' type of classification which utilizes similarities only.

A disadvantage of Linnaeus type of classification is a tendency to use analogous anatomical features and function of the features rather than structure to classify organisms. This mode of classification may lead to results that are contrary to the gradual divergent, parallel or convergent evolutionary models. As explained earlier in chapter 2, there seems to be very close relationships among students' explanations about biological phenomena, students' conceptions related to the nature of biological knowledge, and students' level of biological literacy.
Scientific and Biological Literacy

The NRC (1996) has echoed the BSCS's (1993) call that "the goal of biology education is to promote scientific and biological literacy and enhance students' knowledge about the living world" (p.238). Biological knowledge is also expected to promote students' understanding of biological processes that have resulted in biodiversity. The BSCS (1993) reported that many students entering college have a fragmented knowledge of biology concepts and cannot relate them to one another or to other science content areas.

Definitions of Scientific and Biological Literacy

Scientific literacy is the major goal of biology education. Scientific literacy is defined as the knowledge and understanding of scientific concepts and processes required for personal and public decision making (AAAS, 1989, 1993; Rutherford & Ahlgren, 1990; NRC, 1996). In the words of the AAAS (1993) a scientifically literate person "uses scientific knowledge and scientific ways of thinking for individual and social purposes" (p.11). This definition implies that a scientifically literate person is able to identify scientific issues underlying local as well as national decisions and express positions that are scientifically informed. Scientific literacy also implies that such an individual is able to identify and differentiate scientific from non-scientific ideas.

The increasing numbers of "pseudoscientific" explanations about nature with which students are bombarded every second through the news media and computers necessitates an urgent need for students to develop a "scientific habit of mind" than ever before. With improvements in technology people are
increasingly being bombarded by various forms of prescientific ideas. For instance, students may be misled by astrologers’ claims that their predictions are supported by scientific research. Students need to develop an adequate understanding of the nature of science and the nature of biological knowledge in order to be able to reason logically about issues related to nature and their own lives.

A person with “scientific habits of mind” is in a better position to answer questions related to nature when confronted with issues that demand value judgement. A scientifically literate person uses evidence to logically reason about personal issues. He or she uses facts, scientific principles, and scientific theories to make a judgement on public issues because he/she understand the interactions between science and society.

Levels of Biological Literacy

The development of biological literacy is described as a life-long process in which individual learners progress along a four-level continuum of biological knowledge acquisition, namely, nominal, functional, structural, and multidimensional levels of literacy. Learners show specific characteristics at each level of the biological literacy continuum as they build better understanding and explanations of biological phenomena as follows (BSCS, 1993,p.18).

Nominal Biological Literacy

Nominally literate students have studied biology but have not developed an adequate understanding of the information presented to them. Biological
concepts have no meaning to nominally literate students. Students can identify concepts as biological but provide naive explanations of the concepts. In terms of assessment, students' knowledge at the nominal level of literacy is very shallow, and can only name or list biological concepts without and meaningful understanding of what the concepts mean.

Functional Biological Literacy

Functionally literate students are able to use biological vocabulary but tend to memorize the definitions of concepts so that they have a very limited understanding of their own responses. Such students may be able to "get by" on certain objective questions but may not have an adequate understanding of how relevant the issues in question are to their own life. The NRC (1990) has described biology programs that encourage rote memorization as inadequate since the programs tend to promote only functional literacy and students are unable to apply such knowledge in their day-to-day experiences. The BSCS (1993) used the analogy of a tree, its trunk, branches, and leaves to describe the relationship between biological knowledge, evolutionary concepts, biological principles, and concepts respectively. At the functional level of literacy students may memorize the facts or "leaves" of biology but after the leaves fall off following rote memorization the facts are also forgotten.

Structural Biological Literacy

At the structural level of literacy students develop the conceptual schema of biology and ideas that organize all biological thinking or principles. Structurally literate students are able to explain biological concepts in their own
words. However, at the structural level of literacy, students have only an understanding of the "leaves" or facts of biology and may or may not understand the relationships among the facts or "leaves" are related to the "branches" or biological principles and systems. The BSCS (1993) describes such students as those who may or may not understand the role of the "trunk" or evolutionary biology in keeping all biological knowledge together, and recommends that the best assessment strategy for structural literacy is use of tasks that require students to apply their knowledge to novel situations.

**Multidimensional Biological Literacy**

At the multidimensional level of biological literacy students understand the place of biology among other sciences and disciplines, know the history of biology and understand the interactions between biology and society. Students are able to investigate a problem concerning a local or public issue using the scientific method, and can expand or critique existing knowledge claims. In order to do this students must have the ability to integrate and evaluate biological knowledge with respect to knowledge of other sciences, mathematics, social, and sometimes political issues.

Multidimensional literacy, therefore, requires ability to develop and continually seek to know or acquire thinking skills that allow one to ask appropriate questions related to nature. The BSCS (1993) recommends that multidimensional literacy should be the major goal of biology education. Assessment of multidimensional literacy is conducted by means of action plans in which students logically apply their knowledge by solving local and global
problems. In assessment terms, students in the process of developing multidimensional literacy are identifiable through the kind of questions they ask. They are able to recognize deficiencies existing in their own knowledge of biology. They are also able to recognize pseudoscientific explanations in other people's explanation of natural phenomena and of science as a whole.

**Studies on Students' Levels of Biological Literacy**

Champagne (1989) of the National Center for Improving Science Education stated that "many Americans, even those who are otherwise well educated, have little understanding of science and how it affects their standard of living. Nor do they possess the intellectual skills to act effectively on scientific matters that they encounter in their personal, professional or civic life" (p.419).

Johnson and Peeples (1987) examined college students at a Northern Colorado University to investigate their scientific understanding, level of literacy, and understanding of the nature of science. Students who understood the nature of science discriminated between science and nonscience as stated by Kitcher (1993). These researchers also found that biology major students had a low understanding of science and that students' understanding of the nature of science increased proportionally with students' grade level.

Seniors had a greater understanding of science than freshmen and sophomores. Characteristics of science poorly understood included role of science in understanding the natural world, scientific experimentation, definitions of a theory, and random events. Ewing et al. (1987) studied 126 students in a college introductory biology class at Oklahoma State University to
investigate their attitudes toward biology. Using two single-semester classes of a course which emphasized principles of ecology, genetics, and evolution. Ewing et al. (1987) found that students in the nontraditional class with lectures, small group discussions about critical issues in ecology and evolution and weekly laboratory activities had a better attitude toward biology than those in the traditional lecture and laboratory class. Miller's (1989) study of college students in Northern Illinois University showed that 88% of the students surveyed thought that astrology was based on scientific principles. The same study showed that 63% of the students did not know that dinosaurs became extinct millions of years before the earliest humans roamed the earth.

Using “relevance” as a means of promoting biological literacy, Hoots (1991) studied community college students and found that students only considered the news articles “relevant” to their life as interesting. Hoots’ (1991) study suggests that more “relevant issues” from students’ everyday experiences should be included in science textbooks and lessons in order to encourage scientific literacy among college students.

Lord and Rauscher (1991) surveyed college students in North Eastern College in the U.S to assess students' basic life science literacy on the basis of their age, gender, and science background. The study showed that gender differences existed among male and female students's responses to questions about specific biological issues. All female students were found to provide correct answers to reproductive issues. However, only two thirds of the male students provided the correct responses to those questions. Their study showed
that students tended to learn only biological issues that they considered to be relevant to their lives. Wandersee and Demastes (1992) used information from newspaper articles to address new standards of biological literacy based on relevance of classroom biology. They found that effective discussion strategies, reduction in scope and paring of nonessential terminology and reorganization of the course to include biological situations experienced regularly by students played major roles in students' understanding of the materials students read in newspapers and textbooks. Findings from the above studies confirm statements made by Moore (1983) about the importance of distinguishing science from nonscience and the influence of authority and value-related issues, particularly, when it involves explanations of biological phenomena. Moore (1983) expressed most science educators' concerns about the impact of nonscience on students learning and on the general public in the following statements:

"When contrasting points of view are expressed by individuals both claiming to be scientists, the public is thoroughly confused..... And, to a poorly informed public, the Institute of Creation Research must sound just as reliable and impressive as the National Academy of Sciences or the American Association for the Advancement of Science." (p.93).

In the present study, an assessments of college introductory biology and an advanced zoology students' understanding of the nature of biological knowledge was conducted by examining students' responses to NOBKS questionnaire test items that distinguished science from nonscience. Interview questions complemented the NOBKS questionnaire and probed further students' conceptions related to biological processes.
CHAPTER 3: MATERIALS AND METHODS

Overview of Materials and Methods

In this chapter the research materials and methods are presented beginning with the permission the researcher obtained from the Office of the Dean of the College of Education to conduct research with human subjects prior to the pilot study. Discussions of the development, testing, and validation of the NOBKS questionnaire and student interview questions during the pilot study are presented followed by presentation of the research procedures used during the final study.

In the second section of the chapter, presentation of research procedures begins with the rationale of the quantitative and qualitative methods used are followed by descriptions of the research materials and research settings. Data collection procedures are discussed together with classroom settings, courses used in the study, course instructors, and the student subjects. The quantitative data collection procedures used for the administration of the NOBKS questionnaire to students are then described.

In the third section of the chapter, presentations of the data analysis procedures including descriptive statistical analysis, factor analysis procedures, Pearson's correlation analysis, and multivariate analysis of variance (MANOVA) are made in the order they are used to analyze quantitative data used to answer primary and secondary research questions stated on page 6. The chapter is concluded with a presentation of qualitative procedures, namely, student interviews and content analysis.
Permission to Conduct Study with Human Subjects

In accordance with Louisiana State University System policy regarding research involving human subjects, the researcher and her major professor, as principal investigators, obtained permission to conduct a dissertation study in university classrooms from the office of the Dean of the College of Education. The permission was obtained immediately following committee approval of the research prospectus. This was prior to beginning the pilot study in the fall semester of 1997. A sample copy of the student release forms approved by the Office of the Dean of the College of Education is provided in Appendix A.

Every student who agreed to participate in the study was asked to sign a release form before he/she was allowed to respond to the preliminary questionnaire used in the pilot study and final NOBKS questionnaire used in the final study. Prior to the administration of the preliminary questionnaire, students were informed about the purpose of the study and asked to sign release forms. In order to avoid involving minors in the study, it was emphasized to the all research subjects that only those above 18 years of age would be allowed to participate in the study. A phrase to emphasize the importance of this matter was included on the consent forms (see Appendix B). Students who were willing to volunteer to be interviewed were also asked to indicate this information on their release forms so that they could be contacted by the researcher prior to the interviews.
Description of Pilot Study

The pilot study began in the fall semester of 1997 under the supervision of the researcher’s major professor. Course instructors for introductory biology and zoology courses in the Department of Biological Science at Louisiana State University were contacted for permission to conduct research in their classrooms at the beginning of the semester of 1997. The pilot study began with preliminary observations of the classroom setting, students, instructors, and instructional settings two weeks prior to administering the preliminary pretest research instruments developed during the prospectus using the course syllabi for the two classes. Additional questions and adjustments were made to the preliminary questionnaire through discussions with the introductory biology and advanced zoology course instructors. Appendix C provides the preliminary pilot research instrument from which the final questionnaire was developed.

The preliminary pilot study research instrument is shown in Appendix C consisted of 120 questions which contained 45 multiple-choice questions, each with space at the end of the question for students to state reasons for their choices. It also included 55 3-point categorical questions which required students to use letter A, B, or C depending on their choices. Students were asked to write the letter A against a statement if they “agree” with it, letter B if they “don’t know”, or letter C if they “disagree” with a statement on the questionnaire. Students were also asked to state reasons for their choices. The remaining 20 questions on the preliminary questionnaire instrument consisted of structured questions which required students to respond with short
explanations about specific biological concepts. Data derived from the preliminary pilot study questionnaire were used to identify biology concepts that should be included or excluded from the final NOBKS questionnaire. The pilot study data were also used to refine the instrument by breaking the instrument into two parts.

The first part of the pilot study instrument was refined into a 60-item Likert-scale questionnaire. The second part of the refined instrument consisted of the structured questions retained as complementary questions to the NOBKS questionnaire for use during student interviews. Furthermore, scoring students' responses to the preliminary questionnaire allowed the researcher to assess how clear the individual test questions were to the students. Questions retained in the final instruments were used in both the introductory biology and zoology classes.

Refinement of the structured questions was also achieved by rephrasing and simplifying the statements of both the questionnaire and the standardized interview questions and by excluding questions which were too short or too long to be answered within the time of questionnaire administration. The final NOBKS questionnaire shown in Appendix D and the interview questions shown in Appendix E are products of these refinements. Although the results of the pilot study are not included in this manuscript, the researcher presents the procedures used to develop of the final questionnaire and interview questions in the following sections.
Development of the Final NOBKS Questionnaire

The development of the final NOBKS questionnaire shown in Appendix D from the pilot study research instrument was conducted using suggestions provided by various researchers on the development of a Likert-scale instrument (Hassan & Shrigley, 1984; Koballa, 1984; Koulaidis & Keratsinou, 1988). In consultation with biology and zoology course instructors, the researcher used their course syllabi, information on basic biology content knowledge students exiting high school and entering college are required to know, and the required course texts to refine the preliminary research instrument.

The information on the content knowledge of biology students exiting high school and entering college are required to know was obtained from the guidelines provided in Project 2061's *Benchmarks for Science Literacy* (AAAS, 1993) and the 1998 *Louisiana Science Frameworks* for K-12 grades. The staff members at Louisiana State University's Education Resource Center were very helpful in obtaining the complete 1998 Louisiana Science Framework.

At the beginning of the fall 1997 semester all the 120 questions were given to volunteer 30 volunteer students. Fourteen students were from an introductory biology course, and 16 were from the zoology course. Following this first preliminary administration of the instrument, the researcher found that all the zoology students responded very well to 45 on the multiple-choice questions. About a half of the biology students answered the questions well. Zoology students were either very good at "guessing", very good multiple-
choice "test takers", or their accumulated knowledge of biology rendered the questions very easy for them. The moderately answered questions from the 45 multiple-choice questions were rephrased and retained. Questions which included concepts not covered in the two courses were eliminated altogether from the instrument.

A comparison of the pilot study research instrument provided in Appendix C with the final NOBKS questionnaire in Appendix D should provide the reader with information on the questions that were retained and rephrased or excluded from the final NOBKS questionnaire. The decision to eliminate some of the multiple-choice questions was also reached after the researcher, who at this time was a Graduate Teaching Assistant at the Center for Scientific and Mathematical Literacy, with teaching assignments in the Department of Biological Sciences, consulted with two introductory biology instructors in the Department of Biological Sciences.

The first introductory biology instructor was the researcher's supervisor for the class in which she was a teaching assistant. He was an Assistant Professor and Coordinator of Undergraduate Biology Programs at Louisiana State University. With his permission the preliminary questionnaire and the interview questions had been given to BIOL 1005 the 14 introductory biology students who responded to the preliminary questionnaire during the pilot study.

The second introductory biology instructor consulted was an Assistant Professor teaching a non-science major biology course in the Department of Biological Sciences. Discussions with the two introductory biology professors
prompted further adjustments on the preliminary questionnaire. The researcher was also advised by the two introductory biology professors to consider giving the final NOBKS questionnaire to an introductory biology course for science majors, designated, BIOL 1201 in addition to the advanced zoology course designated ZOOL 3152 which was to be used during the final study. These allowed for better student participation and analysis of findings among the two groups of students.

The third biology instructor consulted by the researcher was the zoology professor in whose class the pilot and final study were conducted. She was a Professor of Zoology. She provided very valuable suggestions towards the refinement of the instrument, including the editing the instrument prior to its transformation into the final NOBKS questionnaire. With the first approval of the preliminary questionnaire and the interview questions, and in order to test further the clarity and reliability of the refined preliminary questionnaire among introductory biology and zoology students, 20 volunteer students were given the questionnaire. Ten were from an introductory biology class and the other 10 were from the zoology class. Students' responses to all the 60 questions ranged from 30% as least score among biology students to 90% as best score among zoology students. The researcher was, however, noticed that the students who scored very low points did not complete some of the structured questions that required a lot of time for students to answer.

The researcher retained and modified these questions into interview questions that would complement the NOBKS questionnaire questions. The
researcher also discovered that the low response rate among students earlier in the semester was due to the fact that the categorical statements with three-point Likert-scale responses included neutral response options in the form "don’t know" which students selected most often when they did not want to respond to certain question. The neutral responses were eliminated and two more scales of "strongly disagree" and "strongly agree" were added to make the final questionnaire a four-point Likert-scale questionnaire. Modifications also included addition of negatively-worded statements to reduce the chance of getting "falsely" correct or incorrect responses from master "test-takers". The final 60-item, four-point NOBKS questionnaire shown in Appendix D.

Part A consisted of general statements related to the general nature of biological knowledge. Part B consisted of general as well as specific statements related to genetic and evolutionary processes. Part B also contained statements about the importance of evolution as the unifying theory of biology. Part C of the questionnaire consisted of statements related to biological classification, homologous and analogous anatomical features as products of evolutionary processes. It also contained statements about the importance of evolutionary models for understanding anatomical or morphological similarities and differences observed among living organisms.

Pretest administration of the final NOBKS questionnaire at the beginning of the spring semester of 1998 revealed that there were better students' responses after the researcher had reduced the number of test items from 120 to 60, rephrased and simplified questions into categorical statements on a four-
point scale, and eliminated neutral responses. Students' choices to the final 60 test items on the final NOBKS questionnaire were restricted and limited to responses that best represented existing conceptions with minimal ambiguity.

Reliability of the final NOBKS Questionnaire

The reliability of the final four-point 60-item Likert-scale NOBKS questionnaire shown in Appendix D was tested by subjecting students' posttest responses to a Cronbach alpha reliability analysis. The General Linear Model of the Statistical Analysis System (SAS, 1996) was used. Likert-scale questionnaire instruments have been reported to be reliable for assessing students' conceptions and general perceptions in educational research (Beech & Harding, 1990; Berdie, Anderson & Neibubr, 1986; Hord, 1987; Koballa, 1984; Likert, 1973).

The Cronbach alpha reliability coefficients of the entire 60-item NOBKS questionnaire was 0.721. The Cronbach alpha reliability coefficients for Parts A, B, and C of the NOBKS were found to be 0.680, 0.720, and 0.765 respectively. These reliability measures were assumed appropriate for use as an assessment instrument due to reasons described by Hatcher (1994). Hatcher (1994) describes questionnaire instruments with a Cronbach alpha reliability coefficients of 0.650 and above as appropriate for use as an assessment instruments. The development of standardized interview questions used to complement students' responses to the 60-item Likert-scale NOBKS questionnaire is also described below.
Development of Standardized Interview Questions

The standardized interview questions shown in Appendix E were developed from structured questions during the pilot study as described earlier. Part 1 of the student interviews consisted of questions related to students' personal, family, science, biological knowledge backgrounds. The purpose for asking these questions at the beginning of the interviews was to confirm the information provided earlier by each student interviewee on their release forms.

Interview questions in parts 2 and 3 corresponded with test items in Part A of the NOBKS questionnaire. Interview questions in parts 4, 5, and 6 were complementary to Part B of the NOBKS questionnaire. Interview questions in parts 7, 8, and 9 complemented to Part C of the NOBKS questionnaire. Interview questions in part 10 were related to students' beliefs, value-related opinions and conceptions. In addition to the interview questions that were derived from the questionnaire test items, specific examples from previous studies (Ameny, 1994; Bunting et al., 1992; Bishop & Anderson, 1990; Demastes, 1994; Lawson' 1994; and Gestaldo et al., 1996) were used. These specific questions related to coevolution, natural selection and genetic mutation, divergent and convergent evolutionary models.

The first specific example which complemented test items in Part B of the NOBKS questionnaire and probed students' level of biological literacy were questions in Part 4 of the student interviews. This question was developed by the researcher to probe students' understanding of genetic mutations and natural selection. It was included in this study for two reasons. Firstly,
discussions with a Museum of Natural Science Professor at Louisiana State University who worked with the researcher in the prospectus stage suggested that students' difficulties with evolutionary mechanism is partly due to students' lack of understanding of the various biological levels of organization. Secondly, a previous study by Kweon (1988) showed that understanding the genetic source of variation helps students to make connections about the levels at which genetic mutations and natural selection occur.

The second specific example specific interview questions shown in Part 5 of student interviews complemented students' responses to the first example described above. It also complemented test items in Part B of the NOBKS questionnaire. It was used to probe students's level of biological literacy using an example from mosquito populations modified from Lawson's (1994). Students were asked to identify and explain the mechanisms responsible for the fluctuation in numbers in a population of mosquitos sprayed with DDT insecticide.

The third specific interview question was Part 6 of the student interviews. This question was modified from Demastes' (1994) study on natural selection. A population of male lions was described and students were asked explain the meaning of "biological fitness". Students were also asked to select the male lion that was most and least "biologically fit" using their understanding of the theory of evolution by natural selection. The fourth specific interview questions, shown as Part 7 of the student interviews was an example modified from Bishop and Anderson's (1990) study on evolution of blindness among cave salamanders.
Students were asked to explain how blindness may have evolved among these salamanders and to predict whether subsequent generations of blind cave salamanders develop sight if the environment of a generation of blind cave salamanders was changed by artificially rearing them in a well-lit laboratory.

The fifth specific interview questions in Parts 8 and 9 of student interviews examined students' understanding of divergent and convergent evolutionary models respectively. They probed students' understanding of the evolutionary history of homologous and analogous anatomical features, biological classification and speciation among organism. These questions also complemented Part C of the NOBKS questionnaire.

The first evolutionary model in Part 8 was a model of divergent evolution modified from Gastaldo et al.'s (1996) textbook, Deciphering the Earths' History. It was designed to probe students' explanation of the evolution of the tail spine, antennae, and eyes among four hypothetical two-body segmented invertebrate species. The second evolutionary model in Part 9 on the interview questions was a model of convergent evolution of organ systems of the gastrointestinal tracts of five domestic vertebrate species including man. This question was derived from the researcher's previous work and Master's thesis (Ameny, 1994) and from her previous mentor's research (Bunting et al., 1992). The model in Part 9 of the student interview emphasized convergent evolution among organ systems of the gastrointestinal tracts of five vertebrate species, as exemplified by the similarities in the functional and physiological similarities among the digestive organ structures of the five vertebrate species. Students were asked to
explain how the functional similarities may have evolved. The last specific interview questions in Part 10 of the interview were developed by the researcher to probe interviewees' overall integration of biological knowledge, level of scientific literacy, and biological literacy. At the time this study was being conducted there was a lot of media coverage going on television, on value-related, and science-technology-society issues. Issues debated on media included those from AIDS/HIV research, medical use of organ transplants from human and non-human donors, and medical use of tissue culture-derived vaccines to treat human diseases.

**Description of the Final Study**

Using the research instruments described above, the final study was conducted in the spring semester of 1998, within a period of approximately 15 weeks. The NOBKS questionnaire was administered twice to both introductory biology and zoology students. However, only posttest responses are reported in this study. Descriptions of the two college classroom settings in which the study was conducted are as provided below.

**Classroom Settings**

Two classrooms, namely the BiOL 1201 and ZOOL 3152 lecture classes were used in this study. The course syllabi and course instructors are described separately in the following section. However, the settings within which the study was conducted warrants a discussion at the beginning of this section. Both introductory biology and zoology lecture classes were three semester credit hours. Biology lectures were held three times a week on Mondays,
Wednesdays, and Fridays. Zoology lectures were held twice a week on Tuesdays and Thursdays. Both lectures lasted about 55 minutes. Zoology lectures were followed immediately by a dissection laboratory class. Observations of the interactions among research subjects during the lecture sessions were conducted in only lecture sessions in the biology classroom. Observations were conducted in both lecture and laboratory sessions in the zoology classroom.

Each class began early in the semester with a discussion of the nature of science, the scientific methods, scientific theories, laws and related concepts. The biology course lectures began with a discussion on the topic "What is life?". The zoology course began with lectures on the topic “What is comparative anatomy”. In subsequent lectures every class period began with a review of concepts discussed in previous lecture periods. The researcher also noted that in both lectures most of the class periods were utilized by instructors for lectures in a more-or-less didactic manner. Students-to-instructor and student-to-student interactions occurred only when the instructors asked questions or when students worked in groups.

**Courses Used in Study**

The two courses used in this study were an introductory biology course for science majors designated, BIOL 1201, and a zoology course in comparative vertebrate anatomy was designated, ZOOL 3152. This introductory biology course syllabus is provided in Table 5.
Table 5: Introductory Biology (BIOL 1201) Syllabus for the 1998 Spring Semester

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Text Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction “What is life?” Biological chemistry Quiz 1</td>
<td>Chapters 1, 2, 3, Chapters 4 &amp; 5, Chapters 1-5</td>
</tr>
<tr>
<td>2</td>
<td>Cells &amp; cellular chemistry</td>
<td>Chapter 7</td>
</tr>
<tr>
<td></td>
<td><strong>First class exam</strong></td>
<td><strong>February 8</strong></td>
</tr>
<tr>
<td>3*a</td>
<td>Cellular metabolism Cellular transport systems</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>4</td>
<td>Quiz 2, Respiration and photosynthesis</td>
<td>Chapters 7 &amp; 8</td>
</tr>
<tr>
<td>5</td>
<td>Molecular biology and genetics</td>
<td>Chapter 15</td>
</tr>
<tr>
<td>6</td>
<td>Recombinant DNA technology</td>
<td>Chapter 16 &amp; 19</td>
</tr>
<tr>
<td></td>
<td><strong>Second class Exam</strong></td>
<td><strong>March 5</strong></td>
</tr>
<tr>
<td>7</td>
<td>Genetics/models</td>
<td>Chapter 17</td>
</tr>
<tr>
<td>8</td>
<td>Gene expression</td>
<td>Chapter 18</td>
</tr>
<tr>
<td>9</td>
<td>Quiz 3, Mitosis,</td>
<td>Chapter 11</td>
</tr>
<tr>
<td>10</td>
<td>Meiosis and Mendelian Genetics</td>
<td>Chapters 12, 13 &amp; 14</td>
</tr>
<tr>
<td></td>
<td><strong>Third class exam</strong></td>
<td><strong>April 7</strong></td>
</tr>
<tr>
<td>11</td>
<td>Population genetics, Evolution</td>
<td>Chapters 20, 21, &amp; 23</td>
</tr>
<tr>
<td>12</td>
<td>Evolution and the environment</td>
<td>Chapter 46</td>
</tr>
<tr>
<td>13</td>
<td>Evolution and ecology</td>
<td>Chapter 47</td>
</tr>
<tr>
<td>14</td>
<td>Community ecology</td>
<td>Chapters 48 &amp; 49</td>
</tr>
<tr>
<td>15*b</td>
<td>Ecosystems, terrestrial, and aquatic systems</td>
<td>Chapter 48 &amp; 49</td>
</tr>
<tr>
<td></td>
<td>Marine systems and contemporary problems</td>
<td>Chapter 47 &amp; 49</td>
</tr>
<tr>
<td></td>
<td><strong>Final Class Exam</strong></td>
<td><strong>May 5</strong></td>
</tr>
</tbody>
</table>

*a pretest and *b posttest administration of the NOBKS questionnaire.
BIOL 1201 was an undergraduate biology course for science majors. Additional required readings to complement class lectures came from the required course textbook *Biology*, sixth edition, by Campbell (1996). Pretest and posttest administration of the NOBKS questionnaire to students in the biology class was done in weeks 3 and 15 of the semester. Pretest and posttest administration of the NOBKS questionnaires in the zoology class were conducted in weeks 2 and 13 of the semester. However, only posttest responses of biology and zoology students' responses to the NOBKS questionnaire are used in the data analysis.

The decision to utilize only posttest results of the study was based on two reasons. First and foremost, because the goal of the study was not to compare the two instructors involved in the teaching on the two courses used in this study, comparison of students' pretest and posttest responses to the NOBKS questionnaire was not conducted. Secondly, further reliability testing of the NOBKS questionnaire during the spring semester of 1998 via Cronbach alpha reliability analysis of students' responses to the final NOBKS questionnaire revealed that students' posttest responses to the final questionnaire were in themselves adequate for answering the research questions for this study. The syllabuses for the introductory and advanced zoology courses were, therefore, considered adequate for comparison of what students had learned prior to and during the semester period of study. The summarized syllabus for the advanced zoology (comparative anatomy) course, designated ZOOL 3152, is provided in Table 6.
Table 6: Summarized ZOOL 3152 Syllabus for the 1998 Spring Semester

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Text Assignments and Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>Definition &amp; types of anatomy, role of genetics and evolution</td>
</tr>
<tr>
<td></td>
<td>“What is comparative anatomy?”</td>
<td>Types of anatomy</td>
</tr>
<tr>
<td></td>
<td>Scientific methods</td>
<td>Role of theory, laws, hypothesis, idea, principle, &amp; concepts</td>
</tr>
<tr>
<td>3</td>
<td>Nature/Philosophy of science and Biology</td>
<td>What is science?</td>
</tr>
<tr>
<td></td>
<td>History of Biology</td>
<td>Aristotle (382-322BC)</td>
</tr>
<tr>
<td></td>
<td>Richard Owen (1804-1832)</td>
<td>Homologous features</td>
</tr>
<tr>
<td></td>
<td>Galen (129-199)</td>
<td>Typology and teleology</td>
</tr>
<tr>
<td>4</td>
<td>Synthetic evolutionary theory (Neodarwinism)</td>
<td>Genetic, anatomical, geological, biochemical, and biogeographical basis.</td>
</tr>
<tr>
<td>5</td>
<td>Evolutionary history of life</td>
<td>Natural selection, speciation, homologous, analogous, derived features etc.</td>
</tr>
<tr>
<td></td>
<td><strong>First lecture Exam</strong></td>
<td><strong>February 13</strong></td>
</tr>
<tr>
<td>6</td>
<td>History of vertebrates</td>
<td>From aquatic, marine to terrestrial environments.</td>
</tr>
<tr>
<td>7</td>
<td><strong>Second Lecture Exam</strong></td>
<td>February 25</td>
</tr>
<tr>
<td></td>
<td>“Who is who” among vertebrates</td>
<td>Geologic time scale</td>
</tr>
<tr>
<td></td>
<td>Biological Classification</td>
<td>Phylum, order, class, family genus, species.</td>
</tr>
<tr>
<td>8</td>
<td>Andrea Vesalius (1514-1564)</td>
<td>Anatomical studies and evidence of evolution</td>
</tr>
</tbody>
</table>

*a Pretest and * bposttest administration of the NOBKS questionnaire

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<table>
<thead>
<tr>
<th>Week</th>
<th>Text Assignments and Concepts</th>
</tr>
</thead>
</table>
| Cuvier (1769-1832) | Founder of paleontology  
Fossil records as evidence of evolutionary change. |
| William Harvey (1645) | Explanation of evolution of the circulatory system |
| 9. Speciation | Speciation models |
| **Third Lecture Exam** | **April 1** |
| 10. Phylogeny and its reconstruction | Plus ecological habitats |
| 11. Anatomical features & Mosaic evolution | Homologous, primitive & derived features. |
| 12. Comparative anatomy of specific organ systems | The integument: skin of fishes, amphibians, reptiles, mammals, birds |
| 13. Terrestrial life support | Limbs as lever systems  
Energy costs & locomotion |
| 15* b. Comparative anatomy of sensory organs  
Feeding mechanisms | Ears of reptiles, birds, and mammals  
With related anatomical features |
| **Comprehensive Exam** | **May 5** |

*a pretest and * b posttest administration of the NOBKS questionnaire.
Assigned readings for the anatomy class were from the required text, *Functional Anatomy of the Vertebrates: An Evolutionary Perspective*, second edition, by Walker and Liem (1994). Required readings for the zoology class were also obtained from several research journals such as *Vertebrates: Physiology*, *American Scientist*, and *Scientific America* to complement class lectures. The dissection laboratory text was *Vertebrate Dissection* (eighth edition), by Walker and Homberger (1992). The syllabus for the laboratory section for the zoology (comparative anatomy) course is not included in this study because the dissection class was taught by a teaching assistant who did not participate in the study.

**Course Instructors**

Both instructors were interested in integrated biological knowledge and its application in understanding biodiversity. Both were also very interested in students' understanding and interpretation of evolutionary and biological processes using biological theories and assumptions behind those interpretations. Both instructors emphasized to their students problems associated with nonscientific reasoning about biological phenomena.

**BIOL 1201 Instructor**

The BIOL 1201 instructor was an Assistant Professor with a Ph.D. in developmental genetics. He had wide experience in the teaching of undergraduate genetics courses despite teaching the BIOL 1201 for the first time during this study. His research interests included using biology to explain how plant cells containing the same genetic information became differentiated
into various cell types such as leaf hairs or trichome, stomatal guard cells, root hairs and unspecialized epidermal cells performing different functions. He considered understanding of evolutionary precursors of these cells and the GL3 genes which appeared to participate in the initiation of the differentiation process as a means of understanding the fate of trichomes. His communication with the researcher indicated that teaching BIOL 1201 afforded him the opportunity to think critically about the basic biological principles he used in his own area of research as he taught students.

The BIOL 1201 instructor approached the study of evolutionary concepts from a very practical perspective using ecology, population genetics, speciation mechanisms, and biogeography to emphasize the evolutionary process. For instance, he used a familiar example of speciation in two populations of rabbits in north and southeast Dakota regions. The biology instructor discussed with students how biologists have used the biological species concept to identify the two species of rabbits. The biology instructor also discussed with his students how a zone of contact between the two distinct species had been demarcated in which no inbreeding occurs among rabbit populations in the two regions.

Even though homologous, and analogous anatomical features were not discussed in the BIOL 1201 class lectures, the researcher's interactions with research subjects revealed that many students had encountered these concept in their high school and other college biology classes. In addition, the discussed with the students who participated in the study the meanings of those terminology during the questionnaire administrations and student interviews.
ZOO1 3152 Instructor

The ZOOL 3152 instructor was a Professor of Zoology with research interests in functional morphology, ecology and evolutionary morphology. She had over fifteen years of teaching at the university level and had taught ZOOL 3152 for over ten years. She had also taught BIOL 1201 in her early years at Louisiana State University.

She had a wide range of research interests including comparative vertebrate anatomy and evolution of structural features, including the accessory structures of the feeding apparatus of birds. At the time of this study she was also teaching an Evolution Seminar related to Functional Morphology, in the Department of Biological Sciences. The biology and zoology students taught by the two instructors are described below.

Research Subjects

During the final study, a total of 150 students responded to the NOBKS questionnaire at pretest. By the end of the spring semester, due to attrition in both classes, only 121 students who responded to the NOBKS questionnaire at posttest. The frequency distribution and complete classification of the research subjects from both the BIOL 1201 and ZOOL 3152 classes are provided later under quantitative results. Students who responded to the questionnaire came from five science two non-science colleges. These students represented both genders, various age groups, majors, and various years in college including graduate school.
Research Procedures

Rationale for Research Procedures

The purpose of this study was to investigate college biology and zoology students' conceptions related to the nature of biological knowledge. Previous conceptual change studies involving assessment of students' understanding of the nature of science have utilized various research methods including quantitative and qualitative methods (Viennot, 1979; Carmazza, McClockey & Green, 1981; Driver, 1981, Champaigne, Gunstone & Klofptter, 1985; Mayer, 1987; Browning & Lehmann, 1989; Good, 1991; Demastes-Southerland, 1994). Gabel (1994) has described conceptual change studies on students' conceptions related to the nature of science under two types of studies, namely, idiographic and nomothetic studies.

In the idiographic method, students' conceptions are analyzed in their own terms. An analysis of individual cases is made to uncover the common features of possible perspectives that students bring to learning situations. In the nomothetic method, students' conceptions are evaluated by their conformity to or deviation from a standard, universally-accepted scientific knowledge. Students' conceptions that differ from universally-accepted scientific knowledge are referred to as misconceptions or alternative conceptions. German philosophers originally described nomothetic research approaches as the most appropriate approach for the natural sciences and idiographic methods as best for the humanities. However, the mixed approach, which utilizes methods similar to idiographic and nomothetic approaches is used in the present study.
This approach is used because of the large number of research subjects. The approach also allows for general patterns in students' scientific and prescientific conceptions to be discovered. Mayr's (1997) has described the distinction between idiographic and nomothetic methods as misleading for research in the biological sciences. This is because research methods adequate for biological sciences utilize approaches used in both the natural sciences and humanities.

Hurd (1993) showed that research in the biological sciences requires an understanding of interactions, relationships, and interconnections among biological systems as well as physical systems and the behavior of these systems. Homberger (1988) described biological research as involving use of descriptive and comparative research methods. In biology education research such research methods translate into an investigation of students' understanding and interpretation of the relationships among biological phenomena and other natural systems. In order to answer the research questions stated on page 6, the researcher chose to use a mixed study design by combining quantitative methods with qualitative approaches.

The researcher's decision to utilize a mixed study design using a Likert-scale questionnaire and student interviews as research instruments was informed by the work of Kuhn (1970) and Toulmin (1972). These philosophers of science recommended that research should be conducted with an established theoretical basis within each discipline. Kuhn (1970) referred to the theoretical basis that drives research as an articulated bias in which in research
findings answer specific questions within specific discipline. In the present study, articulated bias was a result of the biological and zoological perspective employed in the study. The choice of the mixed study design is also guided by the recommendations of various educational researchers (Cronbach, 1980; Fontana & Frey, 1994; Gall, Borg & Gall, 1996; Patton, 1990; Rist, 1982).

Cronbach et al. (1980) recommended that the demand for a study to be "either/or" should be replaced by a desire to utilize a combination of both methods in order to "draw on both styles at the appropriate times and in the appropriate amounts" (p.223). This is because of the fact that each research paradigm addresses specific research objectives. Gunstone (1989) recommended use of both qualitative methods and quantitative methods in studies related to epistemological issues since the issues underlying the researcher's choice of research methods is more complex than the simple demarcation between nomothetic and idiographic terminology.

Rist (1982) suggested that the continued debate regarding the validity and reliability of qualitative and quantitative research approaches are counterproductive to science education research because research questions should direct the choice of research design, procedures and analysis. He described the data derived from each research approach as providing a different slice of reality. Rist (1982) characterized qualitative research as the method for seeking a holistic understanding of the event, situation, or phenomenon being studied. In the holistic approach both quantitative and qualitative methods are utilized. The holistic approach assumes that the overall findings of a study are more
than the sum of the quantitative or qualitative aspects alone. In this approach direct quotations are used to capture research subjects' personal perspectives, opinions and experiences. Field notes, photographs, memos, and other official records become useful pieces of the data collected. Gall et al. (1996) recommended use of qualitative and quantitative research methods so that the findings can complement each other through their respective roles of discovery and confirmation.

Quantitative research utilizes elements of randomization, control, and manipulation of variables so that the researcher views what is being studied independently as external and is able to seek objectivity. Patton (1990) has described the use of both qualitative and quantitative methods and multiple sources of qualitative data as triangulation because the validity and reliability of qualitative research studies are improved when quantitative methods are used to complement qualitative methods whenever possible.

Tashakorie and Teddlie (1997) have recommended use of both qualitative and quantitative methods in educational research because mixed research paradigms involving the determination of both a priori and emerging themes in students' knowledge are common in educational research. Fontana and Frey (1994) referred to use of multiple data sources as multi-method approaches, and reported that mixed research approaches allow the researcher to achieve broader and more meaningful results. In the present study, quantitative methods involved use of a researcher-developed 60-item Likert scale questionnaire referred to as the Nature of Biological Knowledge.
Scale (NOBKS) to collect quantitative data. It was also used at the beginning of student interviews to probe further students’ responses to the NOBKS questionnaire. Student interviews allowed the researcher to employ an interactive research process holding dialogue with selected students from each group, and drawing on specific examples encountered by students from both general biology and comparative vertebrate anatomy classes. Three major assumptions described by Gall et al. (1996) for maintaining the validity of mixed study designs were met in order for the finding of the study to be meaningful.

Firstly, the Likert-scale NOBKS questionnaire yielded categorical numerical scores with a sub-interval scale that can be analyzed by statistical methods. Secondly, each statement on the NOBKS questionnaire represents a biological concept or a prescientific conception with a complementary interview question that can be analyzed qualitatively using content analysis. Thirdly, the researcher’s interaction with students in class and during student interviews allowed her to utilize rich content descriptors as described by Lincoln and Guba (1985). It also allowed the researcher to use examples students encountered during class lectures, and to obtain students’ responses at could not be obtained under strict experimental conditions. Shanker (1989) also suggested that both quantitative and qualitative methods should be used for better understanding of students’ understanding and explanations of evolutionary processes.
Quantitative Procedures

A description and frequency distribution of the students who responded to the NOBKS questionnaire was provided later in Chapter 4. Quantitative analyses of students' posttest responses to the NOBKS questionnaire was conducted by means of descriptive statistics, factor analysis, Pearson's correlations, and multivariate analysis of variance in order to answer the primary and secondary research question stated earlier on pages 6 and 7 of this manuscript.

Descriptive Statistical Analysis

In order to answer primary research questions 1, 2, and 3, descriptive analysis of students' responses to parts A, B, and C were conducted. The General Linear Model of the SAS statistical package (SAS, 1996) was used to conduct all statistical analyses. The descriptive statistics computed included measures of central tendency, namely, students' mean scores of strongly disagree, disagree, agree and strongly agree responses to each NOBKS questionnaire test item. Descriptive analysis of the standard deviation, and standard error of students' each test item was also computed. Results of the descriptive statistics are presented in Chapter 4.

Factor Analysis Technique

The researcher, under the supervision of her major professor, and in consultation with an expert statistician in the Department of Experimental Statistics at Louisiana State University, decided to use factor analysis to explore relationships among students' responses to three parts of the NOBKS
questionnaire since the NOBKS perspectives contained aspects of the general nature of biological knowledge, evolutionary processes, and evolutionary products. Factor analysis was selected as the most appropriate statistical technique because of the rationale of this statistical technique. Factor analysis, by definition, is a multivariate statistical technique used for summarizing information contained in a large number of original variables into a smaller set of variables or factors with minimal loss of information. The four functions of factor analysis include the following (Hair et al., 1995).

1. Verifying the reliability of the instrument on the basis of what constructs are being measured by linear combinations of the constructs in the test items contained in the instrument.
2. Devising a method of combining or condensing large numbers of respondents into distinctly different groups within a larger population.
3. Identifying a set of dimensions that are latent or not easily observed in a large set of variables.
4. Identifying appropriate variables from a much larger set of variables for subsequent statistical analyses such as analyses of variance.
5. Creating an entirely new set of a smaller number of variables to replace the original set of variables so that subsequent statistical analyses can be conducted.

The principal component technique of factor analysis was used in order to compute correlations among students' similar responses. The principal component technique of factor analysis achieves this by computing linear
combinations among similar variables in students' responses. In other words, by this method similarities among students' responses were represented by larger correlation coefficients. Differences among students' responses were represented by smaller factor correlation coefficients. The researcher's decision to use factor analysis to analyze students' responses related to the nature of biological knowledge (Part A), evolutionary concepts (Part B) and homologous and homologous feature (Part C) was inspired by the emphasis placed on the importance of evolution in understanding the nature of biological knowledge in the various educational reform documents (AAAS, 1993; BSCS, 1993; Good et al., 1992; NRC, 1990; NRC, 1996).

This decision was also prompted by the fact that evolution is documented as the cornerstone for biological knowledge (BSCS, 1993), and the fact that several studies have identified students' prescientific conceptions of evolutionary concepts; yet none of the studies available has described concrete relationships among students' conceptions about life, nature of evolutionary processes, and nature of biological knowledge.

**Pearson's Correlation Analysis**

Pearson’s correlation analysis was conducted on the factors extracted by means of factor analysis in order to answer the first secondary research question “How are students' conceptions of the nature of biological knowledge related to their conceptions of evolutionary biology and homologous and analogous anatomical features?”. Conducting Pearson’s correlation analysis was consistent with the following assumptions by Gall et al., (1996, p.427):
1. All the factors extracted must yield continuous scores through the factor loadings. In fact, the factor loadings are in themselves correlation coefficients.

2. The relationships among the factors are assumed to be linear between any two factors considered at a time.

3. The strength indicated by statistically significant p-values, as well as the direction of the relationship among the factors on the correlation matrix provide a means of identifying relationships among variables under consideration.

Gall et al. (1996) and Sirkin (1995) have described Pearson's correlation coefficient, r, as the most stable type of correlation coefficient because it has the smallest standard error.

**Multivariate Analysis of Variance**

Multivariate analysis of variance was also conducted on the factors extracted by means of factor analysis in order to answer secondary research question 2: “Do course, students' age, gender, major, or years in college influence their conceptions related to the nature of biological knowledge?” The General Linear Model procedure of the SAS system (SAS, 1990) was also used for the MANOVA. Statistical studies have shown that when two independent sample means from two populations are being compared in which each group contains only one independent variable, one-way analysis of variance (ANOVA) technique is sufficient for analyzing the data. In ANOVA
design, an investigation of the effect of a single metric or nonmetric independent variable, also called a factor is conducted on a single dependent variable. However, when several sample means are to be compared and several variables are involved as is the case in this study, then a MANOVA should be performed to minimize the chance of committing type 1 error during statistical analysis.

Anderson et al. (1994), Tatsuoka and Lohnes (1988) also describe MANOVA as the best statistical technique to use when a distinction cannot be made between independent and dependent variables as is the case in the present study. The researcher's choice to conduct a MANOVA is also informed by the theoretical basis and advantages of MANOVA as described by Hair et al. (1995) which include the following (p.263):

1. The residual or error variance should be normally distributed. That is, the population from which error variance is determined should be normally distributed since it represents the denominator in the calculation of the F-ratio.
2. The error variance should be equal among the cells, meaning that the variance-covariance matrices within each group is approximately equivalent.
3. Observations within cells should be independent with little correlation among them.

The first assumption was met by use of over 100 data points, that is, 121 students' posttest responses. The second and third assumptions were met by
use of principal component technique of factor analysis. Using MANOVA also allowed for an examination of students' characteristics most associated with the responses observed during the study. Conducting the quantitative data analysis in a sequential order beginning with descriptive statistical analysis, followed by factor analysis, Pearson's correlation analysis, and MANOVA allowed the researcher to systematically answer the primary and secondary research questions stated earlier on page 6. Content analysis of interview responses also complemented the quantitative results as will be described in the next section.

Qualitative Procedures

Students NOBKS questionnaire responses and standardized interviews questions were used to conduct the student interviews. Novak and Gowin (1984) referred to standardized interviews as clinical interviews. Patton (1990) referred to this interview technique as standardized, yet open-ended format of interviewing because in the standardized interview technique, the exact wording and sequence of questions is determined in advance and all interviewees are asked the same or similar questions in the same order. This interview format allows the researcher to compare and contrast individual students' verbal and written responses to identify patterns among the responses. The strengths of the standardized interview format are described by Patton (1990, p. 289):

1. Respondents answering the same questions increases the comparability of the responses.
2. Data are complete for each person on the topics addressed in the interview.

3. It reduces interviewer bias when several interviewers are used.

4. It permits evaluation users to see and review the instrumentation use in the evaluation.

5. It facilitates the organization and analysis of data.

Novak and Gowin (1984) built upon the tradition of Piaget and colleagues and perfected the interview technique as a tool for assessing cognitive function. The clinical interview technique was used for exploring the conceptual framework and reasoning models students used when explaining biological phenomena.

**Description of Student Interviewees**

A total of 20 volunteer students were interviewed. Ten were from the biology class, and 10 were from the zoology (comparative anatomy) class. Ten of the interviewees were females and 10 were males. The interviewees were identified by the same research codes each had been assigned during the NOBKS questionnaire assessment. Biology student interviewees were identified by research codes beginning with the letter B. Zoology interviewees were identified by research codes beginning with the letter Z. For instance, B1 was interviewee number 1 from the biology class, and Z3 is interviewee number 3 from the zoology class. Interviewees' science, biology, and family backgrounds are provided later in Chapter 4 under qualitative results.
The Interview Process

Student interviews were began two weeks before the end of the spring semester. By this time the researcher had already scored the interviewees NOBKS questionnaire responses. With arrangements between the researcher and the individual interviewees, the researcher met privately with those who had signed up on their release forms that they would like to be interviewed. All interviews were conducted in the researchers office in Room 325 Peabody Building.

Special consideration of interviewees' time was made to ensure that each interviewee had at least 45-60 minutes available to sit with the researcher through the entire interview process without any major interruptions. Interviewees who did not have time to be interviewed in the last week before the semester' final examination week were interviewed after the end of the semester. Before every was interview began, the researcher reiterated the purpose of the study and provided each interviewee 5-10 minutes to look his/her NOBKS questionnaire pretest and posttest responses.

This time also allowed the researcher to explain to the interviewee what she would be required to do for the complementary standardized interview questions derived from the NOBKS questionnaire. This "priming period" also allowed every interviewee to adjust to the interview atmosphere, type of questions he/she would be responding to verbally, and in writing, and for the researcher the audio-recording equipment was working before the interview was began.
When the interview began all conversations and verbal responses were tape-recorded for later analysis. Interviews were kept flexible by referring back and forth between students' NOBKS questionnaire responses and the standardized interview questions related to the NOBKS questionnaire test items. In the last part of the interview, the researcher focused on the specific standardized questions to which students were required to write down their responses.

Written interviews included students' reconstruction of phylogenetic relationships among invertebrate and vertebrate species using cladograms. Students were also asked to explain their cladograms verbally. Novak and Gowin (1984) described the main reason for having a focused interview format as "a good means of probing students' cognitive framework, by describing clinical interviews as a means of trying to look into the student's cognitive structure and to ascertain not only the concepts and propositions there are, but also how the concepts are structured and how they can be evoked for problem solving" (p.121).

Focusing on specific standardized interview questions allowed maximum utilization of interview time as suggested by Patton (1990). This qualitative researcher explains that interviews should always "be highly focused so that interviewee time is carefully used" (p.285). The researcher began the interviews by asking the interviewees to describe themselves, how long they had been at Louisiana State University or any other college, their major, what courses they were taking or had completed. This first part of the interview also allowed the
researcher to cross-check the information provided earlier on the release form by each interviewee, and to acquaint herself with the individual interviewees. The student interviews were concluded using the specific interview questions. Students were also asked to explain if the knowledge of evolutionary biology they had encountered during the semester had enhanced their ability to understand the characteristics of living organisms, including ourselves, particularly, as they read newspapers, scientific articles, or listen and watch daily news on radio and television. All the questions in the 10 sections of the student interviews are provided in Appendix E.

Content Analysis of Interview Data

Contents of transcribed students' verbal and written responses to interview questions were analyzed using content analysis as described by Lincoln and Gubba (1985) and Patton (1990). Content analysis was begun by reading through students' interview responses followed by an analysis of concepts used by individual students in their responses to each interview question. Novak and Gowin (1984) referred to this method of content analysis as concept propositional analysis. In concept propositional analyses interview transcripts are analyzed to extract the propositions learners hold.

The analysis process involves organizing students' responses into categories and units to identify common features. In the present study the categories which corresponded with constructs identified by factor analysis of parts A, B, and C or students' conceptions related to the nature of biological knowledge, conceptions related to evolutionary processes, and conceptions
related to homologous and analogous features as products of evolutionary processes were noted. Coded interview transcripts were also unitized to allow the researcher to identify any relationships in students' responses. Coding, categorizing, and unitizing of interview transcripts allowed the researcher to follow up students who provided similar responses in their choices on the NOBKS questionnaire. This also allowed the researcher to match students' responses with those of other interviewees' in order to explore and discover patterns which exist among students' responses. Written interview responses were also analyzed for content by similar methods. Results of the content analysis are provided in Chapter 4 under qualitative results.
CHAPTER 4: RESULTS AND DISCUSSION

Overview of Results and Discussion

In this chapter, quantitative and qualitative results and discussions are presented with respect to the pertinent research questions they answer. These research questions were stated earlier on page 6. Presentation of results begins with quantitative findings followed by those of qualitative findings from student interviews. Presentation and discussion of quantitative findings begin with descriptive statistics results for Parts A, B, and C of the NOBKS questionnaire.

In a sequential manner, the descriptive results are followed by factor analysis results of students' responses to each part of the questionnaire. Together with the complementary student interview results, descriptive and factor analysis results provide answers to research questions to primary research questions 1, 2, and 3. These are then followed by Pearson's correlation analysis result obtained on the analysis of correlations among factors extracted earlier by means of factor analysis. Pearson's correlation analysis results provides answers to secondary research question 1.

The MANOVA results are presented in the last section of quantitative results and discussion in order to answer secondary research question 2. The findings from the quantitative data analysis are then summarized before the presentation of complementary quantitative results from students' interview responses to individual NOBKS questionnaire test items and specific standardized interview questions.
Quantitative Results

Frequency Distribution of Research Subjects

The frequency distribution of the students who responded to the NOBKS questionnaire during this study and the complete classification of the research subjects by gender, course registered in, college, age, and number of years in college is provided in Table 7.

Table 7: Frequency Distribution of the Students who Responded to the NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Category of Students</th>
<th>Number in Sample</th>
<th>Percent (n/N)x100</th>
<th>Total number(%) (N) x100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>70</td>
<td>57.8</td>
<td>121 (100)</td>
</tr>
<tr>
<td>Male</td>
<td>51</td>
<td>42.1</td>
<td></td>
</tr>
<tr>
<td>Course</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIOL 1201</td>
<td>101</td>
<td>83.5</td>
<td>121(100)</td>
</tr>
<tr>
<td>ZOOL 3152</td>
<td>20</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td>College</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>7</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>9</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>†Basic Sciences</td>
<td>93</td>
<td>76.8</td>
<td>121 (100)</td>
</tr>
<tr>
<td>Non-Sciences</td>
<td>12</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-19 years</td>
<td>23</td>
<td>19.0</td>
<td>121 (100)</td>
</tr>
<tr>
<td>20-23 years</td>
<td>81</td>
<td>67.0</td>
<td></td>
</tr>
<tr>
<td>&gt;24 years</td>
<td>17</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Years in college</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshmen</td>
<td>68</td>
<td>56.2</td>
<td>121 (100)</td>
</tr>
<tr>
<td>Sophomores</td>
<td>23</td>
<td>19.0</td>
<td></td>
</tr>
<tr>
<td>Juniors</td>
<td>11</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>Seniors*</td>
<td>19</td>
<td>15.7</td>
<td></td>
</tr>
</tbody>
</table>

†Biology majors comprised the greatest number (66%) of the students from the College of Basic Sciences. *Seniors include graduate students with 4 or more years in college.
Reasons for the categorical breakdown of the research subjects by the various student characteristics become apparent later during the interpretation of MANOVA results. As mentioned earlier, only posttest students' responses of the 121 students who responded to the NOBKS questionnaire were used in this study. The decision to use only posttest responses was based on three reasons. First, the goal of the study was to examine introductory biology and advanced zoology students' conceptions related to the nature of biological knowledge rather than compare the instructor or their instructional methods in the two courses. Secondly, with respect to consideration of conceptual change among the two groups of students, the fact that all advanced zoology students had taken introductory BIOL 1201 prior to registration in ZOOL 3152 deemed the analysis of students' pretest responses unnecessary. Thirdly, preliminary reliability analysis on students' pretest and posttest responses to the NOBKS questionnaire revealed that students' posttest responses adequately answered the research questions stated earlier on pages 6 and 7 of this manuscript. As already mentioned, the actual quantitative results are presented in the order in which they answer primary and secondary research questions beginning with descriptive statistics results.

**Primary Research Question 1**

Primary research question 1 is: "What conceptions related to the nature of biological knowledge do college biology and zoology students hold?" Descriptive analysis results of students' responses to the first twenty test items represented by Part A of the NOBKS questionnaire are provided in Table 8.
Descriptive Statistics Results

Discussions of the descriptive results for each research question are made with respect to students’ agreement responses. These agreement responses include high, moderate and low agreement responses. The high agreement responses represent 80-100% agreement among students’ responses. That is, if 80-100% of the students who participated in the study selected “agree” or “strongly agree” responses to a test item, then a high agreement is assumed to exist among students for that particular test item.

The moderate agreement responses represent 60-79% agreement among students. The low agreement responses represent 0 - 59% agreement among students to the NOBKS questionnaire test items they are associated with. It should be noted, however, that the design of the final NOBKS questionnaire inevitably gave rise to categorical responses in which the intended correct responses for the test items may not necessarily correspond with the agreement responses.

In the design of the questionnaire, neutral choices were eliminated so that students could select only categorical responses that best represented their opinions and conceptions. This was done by eliminating neutral responses options, including positively-worded, and negatively-worded statements. The purpose of using agreement responses in the discussions is to enhance systematic discussion of research findings. Table 8 provides a summary of the descriptive statistics results of students' responses to Part A of the NOBKS questionnaire.
Table 8: Descriptive Statistics Results of Students' Responses to Part A of the NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Test item</th>
<th>Percent SD+D</th>
<th>Percent A+SA</th>
<th>Mean Scores</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80.2</td>
<td>19.8</td>
<td>1.79</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>48.8</td>
<td>51.2</td>
<td>2.48</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>64.5</td>
<td>35.5</td>
<td>2.16</td>
<td>0.86</td>
</tr>
<tr>
<td>4</td>
<td>83.4</td>
<td>16.6</td>
<td>1.80</td>
<td>0.72</td>
</tr>
<tr>
<td>5</td>
<td>7.4</td>
<td>92.6</td>
<td>3.23</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>5.0</td>
<td>95.0</td>
<td>3.45</td>
<td>0.59</td>
</tr>
<tr>
<td>7</td>
<td>3.3</td>
<td>96.7</td>
<td>3.64</td>
<td>0.60</td>
</tr>
<tr>
<td>8</td>
<td>10.7</td>
<td>89.3</td>
<td>3.05</td>
<td>0.63</td>
</tr>
<tr>
<td>9</td>
<td>5.0</td>
<td>95.0</td>
<td>3.18</td>
<td>0.56</td>
</tr>
<tr>
<td>10</td>
<td>4.1</td>
<td>95.9</td>
<td>3.31</td>
<td>0.54</td>
</tr>
<tr>
<td>11</td>
<td>9.1</td>
<td>90.9</td>
<td>3.16</td>
<td>0.62</td>
</tr>
<tr>
<td>12</td>
<td>74.4</td>
<td>25.6</td>
<td>2.00</td>
<td>0.89</td>
</tr>
<tr>
<td>13</td>
<td>49.6</td>
<td>50.4</td>
<td>2.55</td>
<td>0.84</td>
</tr>
<tr>
<td>14</td>
<td>66.1</td>
<td>33.9</td>
<td>2.18</td>
<td>0.81</td>
</tr>
<tr>
<td>15</td>
<td>68.6</td>
<td>31.4</td>
<td>2.08</td>
<td>0.78</td>
</tr>
<tr>
<td>16</td>
<td>43.8</td>
<td>56.2</td>
<td>2.55</td>
<td>0.83</td>
</tr>
<tr>
<td>17</td>
<td>42.1</td>
<td>57.9</td>
<td>2.54</td>
<td>1.00</td>
</tr>
<tr>
<td>18</td>
<td>64.5</td>
<td>35.5</td>
<td>2.19</td>
<td>0.84</td>
</tr>
<tr>
<td>19</td>
<td>35.5</td>
<td>64.5</td>
<td>2.62</td>
<td>0.68</td>
</tr>
<tr>
<td>20</td>
<td>46.3</td>
<td>53.7</td>
<td>2.47</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Where SD = Strongly disagree, D = Disagree, A = Agree, SA = Strongly agree responses, % agreement = %(A+SA), and % in bold type = % intended correct responses.
During the analysis of the descriptive statistics and students' verbal explanations to the same questionnaire test items, the researcher found no verbal consistency in students' written degree of disagreement or agreement responses on the 4-point Likert-scale NOBKS questionnaire. That is, strong agreement responses were expressed similarly to agreement responses and vice versa. Therefore, during analysis students' responses were collapsed into only two major categories, that is, "disagree responses" (from "strongly disagree" and "disagree") and "agree responses" (from "strongly agree" and "agree")

In addition, interpretation of the agreement responses was conducted using high, moderate, and low agreement categories depending on whether or not the agreement responses corresponded with the intended correct answers. The intended correct answer or response to each test item has been printed in bold type under descriptive statistics results. For each of the twenty test items in Part A of the NOBKS questionnaire, which was used to answer primary research question 1, the intended correct categorical responses for each item have been indicated in bold type. If the observed students' agreement responses corresponded with the intended correct answers, then students who agreed with the given statements were assumed to hold scientifically-acceptable conceptions to the phenomena in question. On the other hand, if the observed agreement responses correspond with the incorrect answers, then students who agreed with the given statements in the test items were assumed to hold prescientific conceptions about the phenomenon in question.
Part A: Correct High Agreement Responses

Correct high (80-100%) agreement responses are associated with students’ responses to test items 5, 6, 7, 8, 9, 10, and 11 of part A of the NOBKS questionnaire. The statements contained in the individual test items are re-stated below for ease of reference and interpretation of results.

<table>
<thead>
<tr>
<th>Part A: Correct High Agreement Test items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test item 5: “Biology is a derivative of knowledge from the various life science disciplines”.</td>
</tr>
<tr>
<td>Test item 6: “Biological knowledge is grounded in theories that are supported by scientific research”.</td>
</tr>
<tr>
<td>Test item 7: “Careful observations, hypothesis testing, and conjectures are important in the establishment of biological knowledge”.</td>
</tr>
<tr>
<td>Test item 8: “A complete biological explanation incorporates evolutionary and functional attributes of a biological phenomenon”.</td>
</tr>
<tr>
<td>Test item 9: “Biological sciences answer ‘what’ questions about living organisms”.</td>
</tr>
<tr>
<td>Test item 10: “Biological sciences answer ‘how’ questions about living organisms”.</td>
</tr>
<tr>
<td>Test item 11: “Biological sciences answer ‘why’ questions about living organisms”.</td>
</tr>
</tbody>
</table>

Descriptive statistics results shown in Table 8 show that most of the students who participated in this study agreed with statements about the multilayered nature of biological knowledge as a derivative of knowledge from various life science disciplines (test item 5), the importance of observations,
hypothesis testing (test item 6), and the role of scientific theories in research (test item 7). Since students' high (80-100%) agreement responses with the statements contained in test items 5, 6, and 7 correspond with the intended correct responses. It can, therefore, be assumed that most students who participated in this study understood or held scientifically-acceptable conceptions about the scientific methods used to study biological phenomena.

The high agreement response to test item 8 also suggests that most students have encountered evolution and other unifying principles in their biology courses. Similarly, most students' high agreement responses with test items 9, 10, and 11 suggest that students know that biological sciences can be used to identify, explain, and find logical explanations and reasons for biological phenomena.

The reader should note that test item 11 contained a statement about "why" questions about living things. As indicated with a footnote of the NOBKS questionnaire in Appendix D, this statement was taken from the BSCS (1993) and is used to refer to logical reasons and observable evidence. It is not associated in any way with a religious connotation or "meaning" of the "why" questions. The reader is, therefore, cautioned not to misinterpret it as such. A bar graph representing students' high agreement responses in Part A of the NOBKS is provided in Figure 6 below. Most (80-100%) of the students' who participated in this study provided responses which corresponded with the intended correct response for each test item in Figure 6.
Figure 6: Bar Graph of Correct High Agreement Responses in Part A of the NOBKS questionnaire

In the graph, the similarity in the number of students who provided high agreement responses to test items 5, 6, 7, 9, and 10 suggests that students who understand biology as a multilayered type of knowledge derived from various life science disciplines also understand the scientific methods, role of theories, and how science (biology) tries to find scientific explanations about the natural (living) world.

Factor analysis results also showed that similar correlations among students' responses to these test items as evidenced by the close range in their factor correlation coefficient values. In the same way, the similarity in the numbers of students who agreed with test items 8 and 11 suggests that students answered test items 8 and 11 in a very similar manner suggesting that a relationship may exist among students' conceptions related to complete biological explanations (test item 8) and "why" questions in biology (test item 11). These similarities were also observed following factor analysis.
Part A: Moderate Agreement Responses

Moderate agreement responses were observed among students’ responses to test item 19. The statement in test item 19 is restated below.

Part A: Incorrect Moderate Agreement Test Item

Test item 19: “A theory to biology is what a law is to physics”.

A graphical representation of the proportion of students who incorrectly agreed with the above statement and those who correctly disagreed with the statement in test item 19 is provided in Figure 7 on page 114. Scientific theories and laws are taught and revisited throughout a student’s school life. Most students encounter these concepts as soon as students are introduced to science. This may be as early as the third grade during elementary education. Discussions between the researcher, and her supervisors and research students during interviews show that most of our misunderstanding of the roles of a theory and a law in biology and the other basic sciences may be related to the manner in which these concepts are presented to students during instruction. About 65% of the students incorrectly selected the “agree” response and only 35% correctly selected the “disagree” response.
Students' lack of understanding of the differences between a theory and a law, particularly their use, may suggest three things. First, it suggests a lack of articulation of the roles of a scientific theory and law despite students' repeated exposure to these concepts. Secondly, it may suggest disciplinary differences may exist in the manner in which importance of a law in physics is emphasized compared to the manner in which unifying principles and theories are emphasized in biology.

Thirdly, it may reflect the differences that exist in our understanding of the nature of science within each science discipline. Johnson and Peeples (1987) examined the relationship between students' conceptions of the nature of science and their acceptance of evolution as a biological theory. These
researchers found that students' understanding of the nature of science is related to their understanding of biological processes, particularly, their understanding of the role a biological theory in research.

Using the theory of evolution, Johnson and Peeples (1987) found that many students did not relate the mechanism of evolution, its explanations of the origin of life and evolutionary change to natural processes. These students did not fully understand the nature of science. Their study show that students who do not understand the nature of science do not accept evolution as a biological process.

**Part A: Low Agreement Responses**

Low (0 - 59%) agreement in students' responses were observed in relation to test items 1, 2, 3, 4, 12, 13, 14, 16, 17, 18 and 20. The intended correct responses to the above test items are indicated in bold type in the descriptive results Table 8. The low agreement test items have been divided into correct low agreement responses and incorrect low agreement responses depending on whether or not students' low agreement responses correspond with the intended correct responses. Interpretations of the descriptive results for the low (0-59%) agreement responses have been done bearing in mind the fact that students' agreement responses to those test items, however low the percentages may be, correspond with the intended correct response for these test items. These test items are restated on below.
### Part A: Correct Low Agreement Test items

<table>
<thead>
<tr>
<th>Test item 2: “Biological knowledge provides answers to most questions about the living world”.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test item 3: “Biological sciences cannot answer all questions related to the meaning of life”.</td>
</tr>
<tr>
<td>Test item 4: “Biological sciences cannot answer questions related to human values”.</td>
</tr>
<tr>
<td>Test item 20: “A scientifically literate individual uses biological and other scientific knowledge to make personal and public decisions”.</td>
</tr>
</tbody>
</table>

Students who agreed with the statements in these test items are considered to hold scientifically-acceptable conceptions about the scope and limitations of biological knowledge. Only 0-59% of the students provided correct answers to test items 2, 3, 4, and 20 as shown in the bar graph in Figure 6. These results suggest that less that 60% of the students who participated in this study had scientifically-acceptable conceptions about the scope or limitations of biological knowledge (test item 2). Similarly, less than two-thirds of the students in this study knew that biological sciences cannot answer questions related to the meaning of life (test item 3) or related to human values (test item 4). Only about 54% of the students related scientific literacy to decisions made in ones personal and public life. A graphical representation of the descriptive results of students' correct low agreement responses to the above test items is provided in Figure 8.
On the other hand, these results suggest that more than two-thirds of the students who responded by disagreeing with the above statements hold prescientific conceptions about the limitations of biological knowledge as far as value-related questions are concerned. Even though the low number of incorrect agreements indicate that the remaining majority of the students have some understanding of the concepts associated with these test items, the percentage of incorrect agreements directly represent the number of students in this study who held prescientific conceptions about the phenomena in question. The test items associated with incorrect low agreement responses are restated below for ease of reference.
Part A: Incorrect Low Agreement Test items

Test item 1: “Biological sciences are not grounded in the natural world”.

Test item 12: “All living organisms were created as they appear today by special creation”.

Test item 13: “Evolution is directed towards perfection of organisms by an inherent force in the living organisms”.

Test item 14: "Living and nonliving things are not composed of similar atoms and molecules".

Test item 15: “Living and nonliving things are not subject to the same natural or physical laws”.

Test item 16: "A mystic non-measurable motive force exists in living things".

Test item 17: “The whole organism is no greater than the sum of its parts”.

Test item 18: “Chance plays little role in the changes observed in living organisms.”

About 20% of the students responded incorrectly to test item 1, implying that they perceive biological knowledge as not grounded in the natural world. About 26% of the students incorrectly agreed with the creationist statement in test item 12. Descriptive statistics results also show that students’ responses to test items 13, 16, and 17 were very similar. A graphical representation of the incorrect low agreement responses is provided Figure 9.
About 50%, 56%, and 58% of the students incorrect agreed with the teleological, vitalist, and nonemmergentist statements in these test items 13, 16, and 17 respectively. Similarity also existed among students' responses to test items 14, 15, and 18. About 34% of the students incorrectly agreed with the constitutive reductionist statement in test item 14 and about 31% incorrectly agreed with the nonreductionist statement in test item 15. In the same way, 36% incorrectly agreed with the statement in test item 18. These findings are similar to those of Lawson and Weser (1990) who found that students who employ constitutive nonreductionist reasoning are intuitive, less reflective reasoners. Of even greater concern are the high percentages of students who incorrectly
agreed with the statements in test items 13, 16, and 17. These test items contained statements representing teleological, vitalist, and nonemergentist perspectives about the nature of living organisms. About half (50.4%) of all the students who participated in this study continued to incorrectly agree with the teleological and vitalist statement in test item 13 by the end of a 15-week semester-period of biology instruction. Similarly, 56.2% agreed with the vitalist statement in test item 17 and 57.9% incorrectly agreed with the nonemergentist statement in test item 17.

It is also worth noting here that students who explained during student interviews that they consider life is too complicated to be understood were found to have provided the above incorrect low agreement responses. They also used intuitive reasoning to explain that biology cannot be classified as a natural science in the same way as physics and chemistry. This group of students is exemplified by interviewee B1 whose interview excepts are provided later under qualitative results.

Inspection of her responses in Part A of the NOBKS questionnaire showed that interviewee B1 incorrectly agreed with test items 1, 12, 13, 15, and 16. B1's interview responses about natural selection also included supernatural, predetermined or teleological phrases as will be seen later under qualitative results. The findings of this study are similar to those of Greene (1990) who reported that students' misconceptions or prescientific conceptions tend to follow a logical pattern even if those conceptions do not conform to current scientific conceptions. Greene (1990) also found that students who
provided Lamarckian explanations about natural selection provided teleological explanations about evolution. The students in Greene's study viewed evolution as "directed" change and completely disregarded the selection process. Lawson and Weser (1990) reported similar results.

However, comparing the results of the present study with those of Lawson and Weser (1990) in which about 40% of college non-biology majors were found to hold vitalistic and creationist viewpoints about living organisms, in the present study, a greater number (56%) of students provided responses which suggested that they held vitalist conceptions (test item 16). Secondly, compared to Lawson and Weser's (1990) in which about 20% of the students were found to hold creationist conception, the present study showed that at least 26% of the students held creationist conceptions about the origin of living organisms (in test item 12).

Thirdly, while the students in Lawson and Weser's (1990) study were mainly non-biology majors, the present study was conducted with mostly biology majors in an introductory as well as advanced biology classes. As shown in Table 7 about 66% of the students in this study were biology majors. The findings have conceptual implications of these findings if it is assumed that incremental development of conceptual change occurs proportionally with accumulation of understanding as suggested by the conceptual theory (Posner et al., 1982). On the contrary, findings of this study suggest that "deep" content knowledge may not automatically transfer into conceptual change.
Factor Analysis Results

Factor analysis results of students' responses to Part A of the NOBKS questionnaire showed that three sets of constructs existed among students' responses to Part A of the NOBKS questionnaire. The first set of constructs, also referred to as factor A1 in this study, are related to students' conceptions about scientific methods used in biological research. The second set of constructs identified, designated factor A2 in this study, is related to students' conceptions and beliefs about the origin of life and biological processes. The third set of constructs, referred to as A3 is related to students' interpretations of the scope and limitations of biological knowledge. The Cronbach alpha reliability coefficient recorded for Part A of the NOBKS was 0.761.

Factor A1:

Factor A1 represented constructs related to students' conceptions about scientific methods used in biological research, including observations, hypothesis testing, scientific theories, and laws. Eight of the 20 test items ((test items 5, 6, 7, 8, 9, 10, 11 and 19) in part A of the NOBKS questionnaire loaded under factor A1. Descriptive analysis results of students' responses discussed earlier showed that the first seven test items which loaded on factor A1 had elicited correct high (80-100%) agreement responses among students. The eighth test item elicited a moderate (60-70%) agreement response among students who participated in this study. Factor analysis results of students' responses to Part A of the NOBKS questionnaire are shown in Table 9.
Table 9: Factor Analysis Results of Students' Responses to Part A of the NOBKS questionnaire

<table>
<thead>
<tr>
<th>Test item</th>
<th>Factor A1</th>
<th>Factor A2</th>
<th>Factor A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructs</td>
<td>Students' conceptions related to Scientific methods</td>
<td>Students' beliefs and conceptions about the basis, origin and nature of change in life or biological processes</td>
<td>Students' conceptions or interpretations of the scope and limits of biological knowledge</td>
</tr>
<tr>
<td>1</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>0.14*</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>0.23*</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>0.29*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td>0.25*</td>
</tr>
</tbody>
</table>

All factor loadings were extracted using principal component analysis technique. * Factor loadings below 0.33. Cronbach alpha reliability = 0.761.
The graphical representation of the descriptive results in provided earlier in Figure 6 also showed that there were similarities among students' responses to test items 5, 6, 7, 9, and 10. On the factor analysis matrix the same test items loaded with factor correlations above 0.33 and within the range of 0.64 to 0.78. In the same way there was similarity in students' responses to test items 8 and 11. Student responses to these test items loaded with similar factor correlation coefficients of 0.58 and 0.59 respectively.

While the study shows that students responded with a moderate agreement to the statement in test item 19 under descriptive findings, on the factor analysis matrix test item loaded with a factor correlation coefficient of less than 0.330. This implies that there was a wider variation among students' responses to this test item than among their responses to the other test items under the same factor.

**Factor A2:**

Factor A2 is composed of test items related to basis of biological knowledge, beliefs about the origin of life, composition of living and nonliving things, and the process of change in living organisms. Eight of the 20 test items in part A of the NOBKS questionnaire loaded as Factor A2. These were test item 1, 12, 13, 14, 15, 16, 17 and 18. Descriptive analysis results presented earlier showed that students responded to these test items by incorrectly agreeing with the statements provided in those statements. Six of these items (1, 12, 13, 14, 15 and 18) loaded at or above factor correlation coefficients of 0.33. The remaining two test items (16 and 17) loaded below 0.33.
These factor analysis findings complemented descriptive findings described earlier in which similarities were observed among students' responses to test items 16 (vitalist statement) and 17 (nonemergentist statement). The implications of these findings are twofold. Firstly, it may imply many college students continue have compartmentalized knowledge about the origin of living organisms and other natural systems, particularly, their composition, and the nature of the processes of change that are observed among living and nonliving things.

Secondly, the above results imply that vitalist, creationist, teleological, constitutive nonreductionist, and nonreductionist prescientific conceptions about the origin, change, and composition of living organisms are common among students irrespective of students. Even though instructional methods were not the focus of this study, the findings of this study imply that the instructional methods currently used in college biology classes do not adequately addressing these prescientific conceptions among students. A previous study by Eve and Dunn (1990) showed that many biology teachers have serious questions when it comes to teaching evolutionary concepts. Hence such instructors' ability to address creationist and vitalist prescientific conceptions among their students is greatly impaired by their own prescientific conceptions.

**Factor A3:**

Factor A3 is comprised of students' responses to test items which elicited correct but low agreement responses among students. Four of the test items in
part A of the NOBKS questionnaire loaded on factor A3. They include test items 2, 3, 4, and 20. With the exception of test item 20 which loaded with a factor correlation coefficient below 0.33, all the other three loaded with high correlation coefficients.

These findings are also confirmed by qualitative findings later. Students who hold scientific conceptions about biology and how it helps us to understand the living world related their knowledge of biology to personal and societal issues when explaining what biology is in section 2 of the student interviews. The same students provided explanations that involved used of evidence when responding to questions in section 10 of the student interviews. Those who do not hold scientifically-acceptable interpretations about the scope and limitation of biological knowledge used strongly held personal beliefs to explain personal and public issues in section 10 of the student interviews.

Primary Research Question 2

Primary research question 2 is: "What conceptions related to knowledge of evolutionary biology do biology and zoology students hold?". Descriptive and factor analysis of students' responses to Part B of the NOBKS questionnaire and student interviews provided answers to this research question.

Descriptive Statistics Results

Similar to the analysis of descriptive results for Part A of the NOBKS questionnaire discussed earlier, descriptive analysis of students' responses to Part B of the NOBKS questionnaire is discussed with respect to whether or not the agreement responses correspond with the intended correct answers.
Secondly, the agreement responses are discussed under three categories, namely, high (80-100%) agreement, moderate (60-79%) agreement, and low (0-59%) agreement responses. Results are shown in Table 10 on page 125.

**Part B: High Agreement Responses**

High (80-100%) agreement responses were observed among students' responses to test items 26, 27, 35, and 39. These test items are related to the mechanism of evolution, particularly, the mechanism of natural selection and its relationship to genetic processes, and how as a process it provides a logical explanation about the similarities and differences observed among living organisms. Students' agreement responses to all the four test items corresponded with the intended correct responses.

Students' responses to test items 26 and 27 show that at least 80% of the students who participated in this study have knowledge that natural selection is the main mechanism for biological evolution. Descriptive results also show that most students (over 88%) knew the definition of natural selection (test item 27). This is probably a result of students' frequent encounter with the concept of natural selection in biology courses including the ones in this study. Table 10 provides the descriptive statistics results. Similarly to the descriptive statistics results for Part A of the NOBKS intended correct responses are printed in bold type and the 4-point Likert scale responses have been collapsed to only two major categories of responses as shown in Table 10.
Table 10: Descriptive Statistics Results of Students Responses to Part B of the NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Test item</th>
<th>Percent SD+D</th>
<th>Percent A+SA</th>
<th>Mean Score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>89.2</td>
<td>10.3</td>
<td>1.65</td>
<td>0.71</td>
</tr>
<tr>
<td>22</td>
<td>87.6</td>
<td>12.4</td>
<td>1.83</td>
<td>0.63</td>
</tr>
<tr>
<td>23</td>
<td>52.1</td>
<td>48.9</td>
<td>2.45</td>
<td>0.81</td>
</tr>
<tr>
<td>24</td>
<td>86.0</td>
<td>14.0</td>
<td>1.79</td>
<td>0.72</td>
</tr>
<tr>
<td>25</td>
<td>66.9</td>
<td>33.1</td>
<td>2.20</td>
<td>0.67</td>
</tr>
<tr>
<td>26</td>
<td>14.9</td>
<td>85.1</td>
<td>2.98</td>
<td>0.62</td>
</tr>
<tr>
<td>27</td>
<td>11.6</td>
<td>88.4</td>
<td>3.09</td>
<td>0.59</td>
</tr>
<tr>
<td>28</td>
<td>26.4</td>
<td>73.6</td>
<td>2.85</td>
<td>0.60</td>
</tr>
<tr>
<td>29</td>
<td>24.8</td>
<td>75.2</td>
<td>2.89</td>
<td>0.71</td>
</tr>
<tr>
<td>30</td>
<td>58.7</td>
<td>41.3</td>
<td>2.43</td>
<td>0.76</td>
</tr>
<tr>
<td>31</td>
<td>65.3</td>
<td>34.7</td>
<td>2.29</td>
<td>0.70</td>
</tr>
<tr>
<td>32</td>
<td>41.1</td>
<td>58.9</td>
<td>2.61</td>
<td>0.79</td>
</tr>
<tr>
<td>33</td>
<td>81.8</td>
<td>18.2</td>
<td>1.92</td>
<td>0.71</td>
</tr>
<tr>
<td>34</td>
<td>74.4</td>
<td>25.6</td>
<td>2.07</td>
<td>0.79</td>
</tr>
<tr>
<td>35</td>
<td>16.5</td>
<td>83.5</td>
<td>3.03</td>
<td>0.68</td>
</tr>
<tr>
<td>36</td>
<td>28.1</td>
<td>71.9</td>
<td>2.76</td>
<td>0.67</td>
</tr>
<tr>
<td>37</td>
<td>29.8</td>
<td>70.2</td>
<td>2.97</td>
<td>0.71</td>
</tr>
<tr>
<td>38</td>
<td>70.2</td>
<td>29.8</td>
<td>2.16</td>
<td>0.75</td>
</tr>
<tr>
<td>39</td>
<td>19.0</td>
<td>81.0</td>
<td>2.92</td>
<td>0.63</td>
</tr>
<tr>
<td>40</td>
<td>26.4</td>
<td>73.6</td>
<td>2.82</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Where SD = Strongly disagree, D = Disagree, A = Agree, SA = Strongly agree, and %total agreement = %A+SA, % in bold type = % intended correct responses.
The high agreement test items for Part B of the NOBKS questionnaire (see Appendix D) are restated below for ease of reference.

<table>
<thead>
<tr>
<th>Part B: Correct High Agreement Test Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test item 26: &quot;Natural selection is the primary mechanism responsible for the biological evolution&quot;.</td>
</tr>
<tr>
<td>Test item 27: &quot;Natural selection is the differential survival and reproduction of individual organisms in a population&quot;.</td>
</tr>
<tr>
<td>Test item 35: &quot;Changes in allele frequencies may result from natural selection, migration, genetic drift, or mutation&quot;.</td>
</tr>
<tr>
<td>Test item 39: &quot;The theory of evolution by natural selection provides a logical explanation of the similarities and differences observed among living organisms&quot;.</td>
</tr>
</tbody>
</table>

A graphical representation of students' correct high agreement responses to test items in Part B of the NOBKS is provided in Figure 10 below.

![Bar Graph of Correct High Agreement Responses in Part B of the NOBKS Questionnaire](image)

Figure 10: Bar Graph of Correct High Agreement Responses in Part B of the NOBKS Questionnaire
Students' correct agreement responses to test item 35 also suggests that many students who participated in this study could make connections between genetic and evolutionary processes in terms of changes in allele frequencies. In the introductory biology course used in this study, these concepts were discussed at great lengths. Cummins (1992) found that when genetic and evolutionary concepts are presented to students in the same course rather than separate courses, students are more likely to make connections between proximate genetic and ultimate evolutionary processes.

Part B: Moderate Agreement Responses

Moderate (60-79%) agreement responses are observed in association with test items 28, 29, 36, and 40. All four test items are related to observable influence of natural selection, adaptation, and scientific literacy. A moderate number of students responded correctly to test item 28 which tested their knowledge about the observable influence of natural selection on living organisms.

A moderate number of students also responded correctly to test item 40 which was taken from AAAS 's (1993) definition of scientific literacy. On the other hand, many students responded incorrectly to test item 29. Test items 29 was included in the questionnaire to assess students understanding of the consequences of natural selection on the organisms involved. The correct and incorrect moderate agreement test items are listed below.
Part B: Correct Moderate Agreement Test Items

Test item 28: "Natural selection acts on the phenotypes of living organisms".

Test item 36: "Adaptation as a proximate change is the immediate physiological change observed among organisms in response to change in environment.

Test item 37: "Adaptation as an ultimate change is a gradual process allowing heritable traits to be passed on to next generations".

Test item 40: "A scientifically literate individual displays the scientific habits of mind".

Part B: Incorrect Moderate Agreement Test Item

Test item 29: "Natural selection is always beneficial to the organisms involved".

Graphical representation of students' correct and incorrect moderate agreement responses is shown in Figure 11. Students' incorrect agreement response to test item 29 is shown with an asterisk*.

Figure 11: Bar Graph of Moderate Agreement Responses in Part B of the NOBKS Questionnaire
The researcher's decision to graphically present the correct and incorrect moderate agreement responses together on the same graph is to emphasize the fact that students in this study seemed to hold dual conceptions about natural selection. Some of the students who correctly responded that natural selection acts on phenotypes or observable traits of living organisms also responded incorrectly that natural selection is "always" beneficial to the organisms involved. These findings were also confirmed in students' interview responses and explanations about natural selection. For example, interviewee Z3 selected a correct response to the definition of natural selection, agreed that natural selection acts on phenotypes of living organisms. Yet during interviews she explained that natural selection always benefits the organism. Her interview excerpts are provided later under qualitative results. The conceptual implication of these findings are that students continue to view the mechanism of natural selection from a pre-Darwinian perspective. These findings may also imply that students' understanding of natural selection is quite abstract so that students' view natural selection as having no observable influence on living organisms.

Studies by and Demastes, Good and Peebles (1996) revealed that dual conceptions of evolution exist among biology students. For test items 36 and 37, moderate numbers (about 70%) of students correctly agreed with the statements related to adaptation. Lucas (1971) identified the concept of "adaptation" as a facet that can promote scientific understanding of the evolutionary process. However, he also found that adaptation is a term which is not well articulated by students. Students may end up with several meanings
including Lamarckian, teleological and anthropomorphic interpretations (Good et al., 1992).

It is also alarming to note that up to about 75% of the students who participated in this study incorrectly agreed with the statement in test item 29. This implies that more than three-quarters of the students in this study hold a prescientific conception that natural selection is "always" beneficial to the organisms involved. Biology instruction that utilizes examples from scientists’ experiences and observations on field trips may be needed to promote students’ understanding of natural selection as suggested by Endler (1986).

**Part B: Low Agreement Responses**

Up to eight test items are associated with low (0-59%) agreement among students’ responses. However, similarly to the discussions of low agreement responses for Part A which was used to answer primary research question 1, the low agreement responses for Part B are discussed in terms of whether or not they correspond with the intended correct answers. Students provided correct low agreement responses to test items 30, 31, and 32 restated below.

<table>
<thead>
<tr>
<th>Part B: Correct Low Agreement Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test item 30: &quot;Natural selection is a random process which may be detrimental to the organisms involved&quot;.</td>
</tr>
<tr>
<td>Test item 31: &quot;Natural selection is a random process with neutral consequences on the population of organisms involved&quot;.</td>
</tr>
<tr>
<td>Test item 32: &quot;Because natural selection preserves heritable characteristics all species of living organisms have continued to have similar nucleic acid and anatomical structures&quot;.</td>
</tr>
</tbody>
</table>
Just as students' correct moderate agreement responses pertained to natural selection, students' correct low agreement responses also pertained to natural selection. Again this study showed that students hold various levels of understanding about natural selection. Students' responses to test items 30 and 31 revealed that 25-40% of the students who participated in this study have difficulty understanding natural selection as a random process with neutral or detrimental consequences on the organisms involved.

In fact, over 75% of the students in this study incorrectly agreed with test item 29 (discussed under students' incorrect moderate agreement responses). Comparing students' responses to test item 29 which describes natural selection as a process which always benefits the organisms involved, with their responses to responses to test items 30, 31, and 32 shows that there is a consistency among students' responses to these test items.

These responses suggest that most students incorrectly believe that natural selection is "always" beneficial to living organisms. Students' responses to these test items also suggests that a considerable number of college students hold the prescientific conception that natural selection cannot be detrimental or neutral to organisms. According to these students natural selection is "always" benefits the organisms involved. These findings suggest that at least 59% of college biology students have difficulties understanding evolution as a random process. A graphical representation of students' incorrect agreement responses is provided in Figure 12 below.
Students' interview responses in section 6 of the student interviews complemented their prescientific responses about natural selection. Five out of ten introductory biology and two out of zoology students selected Sandy as the least "biologically fit" because he died early. These students did not consider Sandy's biologically important characteristics such as fathering ability, or average survival rate of his cubs. Findings by Bishop and Anderson (1990) and Demastes (1994) showed that students in their studies had similar prescientific conceptions about the mechanism, process, and consequences of evolution by natural selection.

The fact that natural selection does not have predetermined consequences is succinctly described by Richard Dawkins in his book, The Blind Watchmaker: Why the evidence of Evolution Reveals a Universe Without Design (Dawkins, 1996). Natural selection is described as a blind process with
no predetermined goals and consequences. He compares natural selection to a "blind watchmaker in the following manner: "the blind watchmaker, ........ blind because it does not see ahead, does not plan consequences, has no purpose in view" (p.21). Similarly, students responses to test item 32, which was taken from the NRC (1990, p.23 & 24), in which preservation of heritable traits and presence of similar nucleic acid and body structures among living organisms are presented as evidence for evolution, leaves a lot of questions about students' conceptions relating to the importance and evidence of evolution.

Students provided incorrect low agreement responses to test items 21, 22, 23, 24, 25, and 33. These incorrect agreement test items are related to the importance of evolution in biological knowledge, in addition to the role of variation in the survival of living organisms. The percentage of incorrect agreement responses to these statements directly represent the number of students in this study who held prescientific conceptions about the phenomena in question.

Of most concern in this category was test item 23 to which nearly half of the students in the study incorrectly agreed with the statement about evolution not being the unifying theory of biology. Similarly, up to 33% of the students incorrectly agreed with test item 25 that knowledge of evolution does not transcend interdisciplinary boundaries in the natural sciences. These test items are restated below.
### Part B: Incorrect Low Agreement Test Items

<table>
<thead>
<tr>
<th>Test item</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>&quot;Knowledge of evolution is not important for understanding biological concepts and processes&quot;.</td>
</tr>
<tr>
<td>22</td>
<td>&quot;Knowledge of organic evolution does not add meaning to the concept of change as discussed in biology&quot;.</td>
</tr>
<tr>
<td>23</td>
<td>&quot;The theory of evolution is not the unifying theory of biology&quot;.</td>
</tr>
<tr>
<td>24</td>
<td>&quot;Knowledge of evolution does not enhance one's understanding of the history of life on earth, or the dependence of life on the physical environment&quot;.</td>
</tr>
<tr>
<td>25</td>
<td>&quot;The concept of evolution does not transcend disciplinary boundaries in the natural sciences&quot;.</td>
</tr>
<tr>
<td>33</td>
<td>&quot;Variation plays no role in the survival of individual organisms in a population.</td>
</tr>
<tr>
<td>34</td>
<td>&quot;In the absence of variation, individuals in a population will not become extinct when vast changes occur in the environment&quot;.</td>
</tr>
<tr>
<td>38</td>
<td>&quot;The fact that there is less chance of finding relatively complex fossils in younger sedimentary rocks strata does not support the theory of evolution&quot;.</td>
</tr>
</tbody>
</table>

Test items 23 contained a statement by the AAAS (Rutherford & Ahlgren, 1990, p.69) and from the BSCS (1993, p.20) in which the theory of evolution is described as the unifying theory of biology. The findings of this study show that 49% of the students incorrectly agreed with the statement that evolution is not the unifying theory for biological knowledge. Similarly, 43% of the students in Greene's (1990) study did not see evolution as the unifying theory of biology. This study also showed similarity among students' responses to test items 21, 22, 24, and 33 which shows that between 10-18% of the
biology students who participated in this study believed that knowledge of evolution is not important understanding biology and the nature of biological knowledge. These findings present a great challenge for biology educators since evolution is emphasized as the unifying theory of biology in all science education reform documents. This study shows that many introductory biology students including those who have completed several advanced biology courses did not see the importance of learning evolution in their biology classes. The researcher’s observations revealed that the theory of evolution was covered towards the end of the semester in the introductory biology class. Whereas in the zoology class it was covered at the beginning of the semester and revisited almost throughout the semester. These findings may also imply that based on students’ conceptual ecology, college biology students choose not to accept the theory of evolution as the unifying theory of biological knowledge.

The similarity among students’ responses to test items 21, 22, 24, 25, and 33 also suggest that similar numbers of students hold the prescientific conception that knowledge of evolution is not important for understanding biological concepts or the history of living organisms. The similarity among students' responses in this study to those in Barnett et al.'s (1983) shows that college biology students have poor understanding of evolution as the unifying theory of biology. A graphical representation of students' incorrect agreement responses is provided in Figure 13.
Figure 13: Bar Graph of Incorrect Low Agreement Responses in Part B of the NOBKS Questionnaire.

Cummins and Remsen (1992) suggested that students' view that the theory of evolution by natural selection is not the unifying theory may be due to the overemphasis of biological concepts that deal with proximate causation. Little emphasis of evolution in biology during instruction, coupled with poor coverage of ultimate evolutionary processes place students at a disadvantage of not being exposed to the evolutionary basis of biological knowledge. The above descriptive findings are supported by the factor analysis results of students responses to Part B of the NOBKS questionnaire.

Factor Analysis Results

Factor analysis results identified two sets of constructs from students responses to Part B of the NOBKS questionnaire. The factors associated with each set of constructs loaded on the factor analysis matrix depending on
whether students provided correct and incorrect responses to the 20 test items in Part B of the NOBKS questionnaire. Students' responses associated with incorrect moderate and low agreement responses loaded as factor B1 on the factor analysis matrix.

Students' responses associated with correct high and moderate agreement responses loaded as factor B2 on the factor analysis matrix. The test items which loaded as loaded as factor B1 included 21, 22, 23, 24, 25, 29, 33, 34, and 38. Those which loaded as factor B2 included 26, 27, 28, 30, 31, 32, 35, 36, 37, 39, and 40. Factor analysis results of students' responses to Part B of the NOBKS questionnaire are provided in Table 11 below.

**Factor B1:**

Students' responses to test items related to the importance or consequences of evolution were identified on the factor matrix as factor B1. All the statements on the test items were negatively-worded statements. The clustering of students' responses to these test items with all factor correlation coefficient values above 0.33 suggests that similarity existed among students' responses to these test items.

For factor B1, there is a close range among the factor analysis correlation coefficients of students' responses to test items 21, 22, 23, 24, 25, 33, 34, and 38 ranging from a factor correlation coefficient of 0.60 for test item 24 to a factor correlation coefficient of 0.73 for test item 38. Factor correlation coefficients for the remaining factor B1 test items are between the two coefficients.
Table 11: Factor Analysis Results of Students' Responses to Part B of the NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Test items/Constructs</th>
<th>Students' conceptions of the importance and the consequences of the evolutionary processes</th>
<th>Students' conceptions of natural selection and related evolutionary concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.30*</td>
<td></td>
</tr>
</tbody>
</table>

All factor loadings were extracted using principal components factor analysis technique, rotated orthogonally, and varimax. * Factor correlation coefficients below 0.33. Cronbach alpha correlation coefficient = 0.700
There was a comparatively lower correlation coefficient (0.45) for test item 29. This finding is consistent with descriptive statistics results discussed earlier. With the exception of test item 29 to which students provided incorrect moderate agreement responses. Students' responses to the rest of factor A1 test items were incorrect low agreement responses. The lower factor correlation coefficient among students' responses to test item 29 also implies that there was less similarity or more variation among students' responses to test item 29.

**Factor B2:**

The rest of the test items in Part B of the NOBKS questionnaire which did not load as factor A1 loaded as factor B2. These test items included 26, 27, 28, 30, 31, 32, 35, 36, 37, 39, and 40. Under descriptive results, students' responses to these test items were in the correct high agreement (test items 26, 27, 35, and 39), correct moderate agreement (test items 28, 36, 37, and 40), and correct low agreement (test items 30, 31, and 32) categories. The similarity among correlation coefficients related to test items in each category also confirm the reliability with which the NOBKS questionnaire assessed students' conceptions. The Cronbach alpha reliability coefficient for Part B of the NOBKS questionnaire was 0.700 compared to the overall reliability of 0.730 for the entire 60-item NOBKS questionnaire as a research instrument.

**Primary Research Question 3**

Primary research question 3 is: “What conceptions related to knowledge of homologous and analogous anatomical features do biology and zoology students hold?”. Descriptive analysis of students' responses to Part C of the
NOBKS questionnaire complemented by factor analysis and student interviews, provided answers to this research question.

**Descriptive Statistics Results**

Similar to the descriptive analysis of students' responses to Parts A and B of the NOBKS questionnaire discussed earlier, descriptive analysis results for students' responses to Part C of the NOBKS are presented with respect to three categories of agreement responses, namely, high, moderate, and low agreements. High agreement represents 80-100% agreement among students' responses.

Moderate agreement represents 60-79% agreement among students' responses. Low agreement represents 0-59% agreement among students' responses. Results of the descriptive analysis of students' responses to Part C of the NOBKS questionnaire are provided in Table 12. Intended correct responses are indicated in bold type.

**Part C: High Agreement Responses**

Correct high agreement (80-100%) responses were observed among students' responses to test items 41, 46, 49, 53, 54, 57, 59, 60. These test items are related to the role of evolutionary models in understanding biological classification. It should be noted that test items 41, 49, 53, and 64 contain statements related to evolution. Descriptive analysis results shows that students' responses to all the high agreement test items correspond with the intended correct responses. Most (80-100%) students correctly agreed with the statements in the above test items.
Table 12: Descriptive Statistics Results of Students' Responses to Part C of the NOBKS Questionnaire.

<table>
<thead>
<tr>
<th>Test item</th>
<th>Percent SD+D</th>
<th>Percent A+SA</th>
<th>Mean Score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>17.5</td>
<td>82.5</td>
<td>2.90</td>
<td>0.55</td>
</tr>
<tr>
<td>42</td>
<td>25.6</td>
<td>74.4</td>
<td>2.57</td>
<td>0.57</td>
</tr>
<tr>
<td>43</td>
<td>42.1</td>
<td>57.9</td>
<td>2.59</td>
<td>0.64</td>
</tr>
<tr>
<td>44</td>
<td>36.4</td>
<td>63.6</td>
<td>2.59</td>
<td>0.62</td>
</tr>
<tr>
<td>45</td>
<td><strong>38.8</strong></td>
<td>61.2</td>
<td>2.62</td>
<td>0.60</td>
</tr>
<tr>
<td>46</td>
<td>12.4</td>
<td>87.6</td>
<td>3.12</td>
<td>0.67</td>
</tr>
<tr>
<td>47</td>
<td>57.8</td>
<td>42.2</td>
<td>2.34</td>
<td>0.79</td>
</tr>
<tr>
<td>48</td>
<td>73.6</td>
<td>26.4</td>
<td>2.18</td>
<td>0.69</td>
</tr>
<tr>
<td>49</td>
<td>19.0</td>
<td>81.0</td>
<td>2.94</td>
<td>0.67</td>
</tr>
<tr>
<td>50</td>
<td>33.1</td>
<td>66.9</td>
<td>2.78</td>
<td>0.68</td>
</tr>
<tr>
<td>51</td>
<td>79.3</td>
<td>21.5</td>
<td>2.01</td>
<td>0.76</td>
</tr>
<tr>
<td>52</td>
<td>72.7</td>
<td>27.3</td>
<td>2.13</td>
<td>0.75</td>
</tr>
<tr>
<td>53</td>
<td>19.8</td>
<td>80.2</td>
<td>2.85</td>
<td>0.62</td>
</tr>
<tr>
<td>54</td>
<td>18.8</td>
<td>80.2</td>
<td>2.82</td>
<td>0.72</td>
</tr>
<tr>
<td>55</td>
<td>59.5</td>
<td>40.5</td>
<td>2.34</td>
<td>0.84</td>
</tr>
<tr>
<td>56</td>
<td>80.1</td>
<td>19.9</td>
<td>1.86</td>
<td>0.78</td>
</tr>
<tr>
<td>57</td>
<td>19.8</td>
<td>80.2</td>
<td>2.97</td>
<td>0.68</td>
</tr>
<tr>
<td>58</td>
<td>74.4</td>
<td>25.6</td>
<td>2.12</td>
<td>0.66</td>
</tr>
<tr>
<td>59</td>
<td>10.7</td>
<td>89.3</td>
<td>3.26</td>
<td>0.64</td>
</tr>
<tr>
<td>60</td>
<td>16.5</td>
<td>83.5</td>
<td>3.14</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Where SD = Strongly disagree, D = Disagree, A = Agree, and SA = Strongly agree responses, and %total agreement = % (A+SA), % in bold type = intended correct responses.

The correct high agreement test items for Part C of the NOBKS questionnaire are restated below.
### Part C: Correct High Agreement Test Items

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>“Systematic classification of living organisms makes more sense when their evolutionary history are considered”.</td>
</tr>
<tr>
<td>46</td>
<td>“Understanding the history of biology and the modes of thought used by founder biologists enhances our understanding of biology as a way of knowing”.</td>
</tr>
<tr>
<td>49</td>
<td>“Homologous features are found in two or more taxa or species, and are traceable to similar features in intermediate ancestors”.</td>
</tr>
<tr>
<td>53</td>
<td>“Homologous and analogous anatomical features observed in two or more species are products of evolutionary processes”.</td>
</tr>
<tr>
<td>54</td>
<td>“Most if not all concepts in biology make more sense “in the light of evolution”.</td>
</tr>
<tr>
<td>57</td>
<td>“Scientific knowledge usually surprises us if we discover that our world is not as we perceive it to be”.</td>
</tr>
<tr>
<td>59</td>
<td>“Evidence and theories drive biological research”.</td>
</tr>
<tr>
<td>60</td>
<td>“Scientific knowledge sometimes forces us to discard beliefs we have long held about the grand scheme of nature”.</td>
</tr>
</tbody>
</table>

The bar graph shows similarities among students' responses to test items 46 and 59. It also shows that similarities exist among students' responses to test items 41, 46, 49, 53, 54, 57, 59, and 60. All these eight high agreement test items in Part C of the NOBKS questionnaire loaded as Factor C1 along with students' correct moderate agreement responses on the factor analysis matrix. By way of their correlation coefficients, a close range is observed among the factor correlation coefficients associated with test items. Figure 14 provides a graphical representation of students' responses to the above test items.
Part C: Moderate Agreement Responses

Moderate (60-79%) agreement among students' responses were observed in relation to test items 42, 44, 45, 50. All these test items contain statements describing evolutionary models that explain the origin of the similarities in structure (homology) and function (analogy) observed among living organisms. Because these test items consist of statements describing comparative evolutionary models, they indirectly relate to scientific methods. The moderate agreement test items are restated below for ease of reference.

Figure 14: Bar Graph of Correct High Agreement Responses in Part C of the NOBKS Questionnaire
### Part C Correct Moderate Agreement Test Items

Test item 42: “Convergent evolution explains the existence of similar functional (analogous) features among organisms living in the same environment”.

Test item 44: “Divergent evolution is responsible for similarities in homologous structural features among living organisms”.

Test item 50: “Analogous features in two or more taxa or species perform similar functions but are not traceable to similar features in their immediate ancestors”.

### Part C Incorrect Moderate Agreement Test Items

Test item 45: “Teleology adequately explains the structural similarities observed in populations of living organisms”.

Of major concern is the 61% incorrect students’ agreement response to test item 45 were in the incorrect moderate agreement category. About 61% of the students incorrectly agreed with the explanation that teleology or predetermined changes are responsible for the development of structural features that are observed in living organisms. However, factor analysis results showed little similarity (factor correlation coefficient of 0.46) among students’ responses to test item 45. This implies two things. Either students did not understand the meaning of the term teleology, or if they did, they incorrectly agreed with the statement. Graphical representation of students’ correct and incorrect moderate agreement responses to the above statements is provided in Figure 15.
For students in the zoology class who discussed the concept of teleology and the problems associated with teleological thinking in their comparative anatomy course, the similarities observed among their correct responses to test items 42, 44, and 50, and incorrect responses to test item 45* (in asterisk in Figure 15) may imply lack of articulation during instruction.

Part C: Low Agreement Responses

Students responded with low agreements to test items 43, 47, 48, 51, 52, 55, 56, and 58. However, depending on whether or not they correspond with the intended correct answers students' low agreement responses have been divided into correct and incorrect agreement responses. Students' low agreement responses to test items 43 and 55 corresponded with the intended correct answers. On the other hand, students' low agreement responses to test
items 47, 48, 51, 52, 56, and 58 did not correspond with the intended correct responses. The test items to which students responded with low agreement are restated below beginning with those of correct low agreement.

**Correct Low Agreement Test Items**

Test item 43: "Divergent evolution is responsible for the observed similarities in homologous structural features among living organisms".

About 58% of the students correctly agreed with the statement in test item 43. Students' interview responses to standardized questions in sections 8 and 9 confirmed students' lack of understanding of evolutionary models. Figure 16 provides a graphical representation of students' responses to test item 43.

![Bar Graph of Correct Low Agreement Responses in Part C of the NOBKS Questionnaire](image)

**Figure 16: Bar Graph of Correct Low Agreement Responses in Part C of the NOBKS Questionnaire**
During the student interviews, zoology students who provided incorrect answers to test item 43 also provided incorrect reconstructions of divergent evolutionary relationships among the hypothetical invertebrates in section 8 of the student interviews. Similarly, zoology students who did not understand convergent evolutionary models showed inaccurate relationships among the domestic vertebrate species in section 9 of the student interviews. Introductory biology students’ interview responses to the evolutionary models in sections 8 and 9 were not analyzed because most of these students had not covered these concepts in their biology course.

Ashlock (1979) and Mayr and Ashlock (1991) have reported that understanding divergent and convergent evolutionary models promote the understanding of speciation and biological classification. Homberger (1997) explains that use of evolutionary models has been adopted by most systematists and comparative anatomists because the potential these models have in explaining structural similarities and differences among organisms.

Descriptive analysis also showed that students provided incorrect low agreement responses to test items 47, 48, 51, 52, 55, 56, 58 of Part C of the NOBKS questionnaire. Students' agreement responses to these test items did not correspond with the intended correct answers. Students who agreed with these test items were, therefore, assumed to hold prescientific conceptions to the concepts contained in those test items. The statements contained in these low agreement test items are restated below.
Incorrect Low Agreement Test Items

Test item 47: “Meaningful understanding of biological knowledge is not inherently based on an understanding of the historical nature of biology”.

Test item 48: “Meaningful understanding of biology is not inherently based on evidence supporting observed characteristics of living organisms”.

Test item 51: “An understanding of evolutionary biology does not enhance one’s understanding of comparative anatomy, physiology, and biochemistry”.

Test item 52: “Knowledge of microevolutionary and macroevolutionary changes are not complementary to meaningful understanding of biology”.

Test item 55: “The probability that natural selection could build an anatomical structure as complex as an eye is equal to the probability that a hurricane could pass through a junkyard and build a 747”.

Test item 56: “Competition plays no role in the evolutionary process”.

Test item 58: “Scientific knowledge rarely troubles us if we discover that our world is not as we perceive it to be”.

With the exception of test item 55, statements in all the other test items are negatively-worded. The percentage of students who incorrectly agreed with these statements is a direct representation of the percentage of students in this study who held prescientific conceptions about the phenomena in question. Figure 17 provides a graphical representation of students' incorrect low agreement responses in Part C of the NOBKS questionnaire.
The study shows that about 42% of the students in this study did not know that biology has a historical nature (test item 47). Students' agreement responses to test item 55 were also in the incorrect low agreement category. Test item 55 assessed students' use of probability reasoning in relation to biological processes. Descriptive analysis of students' responses to test item 55 showed that 40% of the students incorrectly agreed with the probability statement provided.

These students had the opinion that by chance alone the probability of a physical force from, say, a hurricane or earthquake developing into a very destructive force was higher than that of a complex structure like an eye developing in living organism. Students' expressed the opinion that "force" must be present for anything "unique" or "drastic" in nature. This prescientific
conception about chance may be related to students' vitalist conceptions. In an interview response to test item 55, interviewee Z3 (see page 178) from the comparative anatomy class expressed the opinion:

"The more I see the complexity of the anatomical structures I am dissecting, the more I doubt if evolution is really responsible for putting all those structures together in the right place for every organism".

This statement implies that Z3 believed that by chance alone no such complex systems as those observed in organisms could have evolved. It also implies that Z3 believed in "intelligent design" or creationism. The rest of her statements are provided under qualitative results. About 26% of the students incorrectly agreed with the statement: "Scientific knowledge rarely troubles us if we discover that our world is not as we perceive is to be" (test item 58). It is interesting to note that the same number of students (26%) incorrectly agreed with the creationist statement in test item 12 in Part A of the NOBKS questionnaire. The above descriptive results of students' responses to test items in Part C of the NOBKS questionnaire are supported by the factor analysis results.

**Factor Analysis Results**

Two sets of constructs were identified among students' responses to Part C of the NOBKS questionnaire. These constructs are represented by factor C1 and factor C2. Table 13 shows factor analysis results of students' responses to Part C of the NOBKS questionnaire. The Cronbach alpha reliability coefficient at which factors C1 and C2 were extracted was 0.731.
Table 13: Factor Analysis Results of Students’ Responses to Part C of the NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Test item</th>
<th>Constructs</th>
<th>Factor C1: Role of evolutionary models in understanding biological classification</th>
<th>Factor C2: Role of evolutionary models in understanding homologous and analogous structural features</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td></td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
<td>0.45</td>
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<tr>
<td>43</td>
<td></td>
<td></td>
<td>0.30*</td>
</tr>
<tr>
<td>44</td>
<td></td>
<td>0.69</td>
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</tr>
<tr>
<td>45</td>
<td></td>
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</tr>
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<td>46</td>
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<td>0.53</td>
</tr>
<tr>
<td>48</td>
<td></td>
<td></td>
<td>0.66</td>
</tr>
<tr>
<td>49</td>
<td></td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>0.47</td>
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</tr>
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<td></td>
<td></td>
<td>0.57</td>
</tr>
<tr>
<td>53</td>
<td></td>
<td>0.34</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>0.49</td>
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<tr>
<td>60</td>
<td></td>
<td>0.57</td>
<td></td>
</tr>
</tbody>
</table>

All factor loadings were extracted using the principal components technique of analysis. * Factor correlation coefficients below 0.33. Cronbach alpha reliability coefficient = 0.731.
Factor C1

Factor C1 is comprised of test items related to students' understanding of the role of evolution in understanding biological classification. Eleven test items in Part C of the NOBKS questionnaire loaded as factor C1. These test items included 41, 42, 44, 45, 46, 49, 50, 53, 54, 57, 59, and 60. Descriptive analysis results previously showed that factor C1 test items were associated with students' high and moderate responses. These test items contained statements that assessed students' understanding of the role of evolutionary models in understanding of biological classification.

Factor C2

Factor C2 is related to test items which assess students' understanding of the role of evolution in understanding homologous and analogous structural features among living organisms. Students' responses to 9 test items in Part C of the NOBKS questionnaire loaded as factor C2 on the factor matrix. These test items include 43, 47, 48, 51, 52, 55, 56, and 58. This test items were related to students' understanding of the role of evolutionary models in understanding homologous and analogous structural features.

Secondary Research Question 1

Secondary research question 1 is: "How do students' conceptions of the nature of biological knowledge, relate to their knowledge of evolutionary biology and knowledge of homologous and analogous anatomical features?" This research question was answered by means of Pearson's correlation analysis conducted on the factors extracted by means of factor analysis.
### Pearson's Correlation Results

Pearson's correlation analysis results are shown in Table 14 below.

#### Table 14: Results of Pearson's Correlation Analysis on Factors Extracted from Students Responses to Parts A, B, and C of the NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Factors</th>
<th>A1</th>
<th>A2†</th>
<th>A3</th>
<th>B1†</th>
<th>B2</th>
<th>C1</th>
<th>C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
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<td>0.06</td>
<td>0.08</td>
<td>0.18</td>
<td>0.31</td>
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<td>0.07</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
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<td>(121)</td>
<td>(120)</td>
<td>(121)</td>
<td>(120)</td>
<td>(119)</td>
<td>(121)</td>
</tr>
<tr>
<td>A2†</td>
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<td>-0.37</td>
<td>-0.26*</td>
<td>0.13</td>
<td>-0.17*</td>
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<tr>
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<td>0.00</td>
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<td>0.01</td>
<td>0.0001</td>
<td>0.05</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
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<td>(120)</td>
<td>(121)</td>
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<td>0.00</td>
<td>0.43*</td>
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<td>0.0001</td>
<td>0.03</td>
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<td>(121)</td>
<td>(121)</td>
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<td>-0.63*</td>
<td>-0.63*</td>
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<td>(121)</td>
<td>(121)</td>
<td>(121)</td>
<td>(121)</td>
<td>(121)</td>
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<td>B2</td>
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<td>0.00</td>
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<td>C1</td>
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<td>0.00</td>
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<td>0.26*</td>
<td>0.26*</td>
<td>0.26*</td>
<td>0.26*</td>
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<tr>
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<td>(120)</td>
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<td>(121)</td>
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<td>(121)</td>
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<tr>
<td>C2</td>
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<td>(121)</td>
<td>(121)</td>
<td>(121)</td>
<td>(121)</td>
</tr>
</tbody>
</table>

Where (n) = number of students' responses on which the correlation is based, and *p-value = 0.0001 for a statistically significant correlation. B1† = factor representing negatively-worded statements which de-emphasize importance of evolution. A2† = factor representing students' prescientific beliefs and conceptions.
The table represents the relationships that exist among the seven factors or sets of constructs extracted from students' responses to the three parts of the 60-item NOBKS questionnaire. From students' responses to Part A of the NOBKS questionnaire, three factors were extracted namely, factors A1, A2, and A3. These three factors from Part A of the questionnaire corresponded with concepts related to scientific methods (factor A1), beliefs about the origin of life and biological processes (factor A2), and students' conceptions related to the scope and limits of biological knowledge (A3). From students' responses to Part B of the questionnaire, two factors B1 and B2 were extracted. The two sets of factors or constructs represented students' conceptions related to natural selection (factor B1) and students' conceptions related to the importance and consequences of evolutionary processes (factor B2).

Finally from students' responses to Part C of the NOBKS related to students' conceptions about the role of evolutionary models in understanding biological classification (C1), and the role of evolutionary models in understanding similarities (homology) and differences (analogy) in structural features among living organisms (C2).

With the above sets of constructs in mind, Pearson's correlation analysis results show that statistically positive correlations existed among factors most factors, namely, between factors .A1 and C1, A1 and C2, A2 and A3, A2 and B2, A3 and B1, B1 and C2, B2 and C1, and between C1 and C2. On the other hand statistically significant negative correlations were observed between factors A2
and B1, and between A3 and C2. In the interpretation of the negative correlation between factors A2 and B1, the reader should note that negative correlation between these two factors is due to the fact that factor A2 test items were positively-worded while factor B1 test items were negatively-worded statements. The negative correlation between factors A2 and B1, therefore, imply that students who responded by incorrectly agreeing with statements related to beliefs about the origin of life and nature of change in biological processes or factor A2 (which were all incorrect low agreement responses comprised of test items 1, 12, 13, 14, 15, 16, 17, and 18), also provided the incorrect responses to test items related to the importance and consequences of evolutions or factor B1 (comprised of test items 21, 22, 23, 24, 25, 29, 33, 34, and 38, which were also incorrect low agreement test items).

The negative correlation between factor A3 and factor C3 can be interpreted similarly. Students who responded by agreeing incorrectly with factor A3 (test items 1, 12, 13, 14, 15, 16, and 17) also incorrectly agreed with factor C2 (test items 45, 47, 48, 51, 52, 55, 56, and 58) which represented the set of constructs related to importance of evolutionary models in understanding homologous and analogous features or similarities and differences among organisms.

The conceptual implications of these Pearson's' correlation analysis findings are that students who do not understand the importance of the theory of evolution by natural selection (factor B1) hold prescientific conceptions and beliefs about the origin and nature of change in living organism (factor A2).
These prescientific conceptions have been identified in this study to include creationism, vitalism, nonreductionism and nonemergentism. Similarly, students who hold prescientific beliefs or conceptions (factor A3) do not understand the importance of evolutionary models (factor C2) for understanding homologous and analogous features. Such similarities and differences among organisms are studied in identified in comparative studies such as comparative anatomy, biochemistry, etcetera.

Secondary Research Question 2

Secondary research question 2 is: "Do course, students' age, gender or years in college influence students' conceptions related to the nature of biological knowledge?" As mentioned earlier in Chapter 3, secondary research question 2 was answered by use of multivariate analysis of variance. Similarly to the Pearson's correlation analysis, multivariate analysis of variance or MANOVA was conducted on the factors extracted by means of factor analysis in order to answer this research question.

MANOVA Results

Students' characteristics that were included in the MANOVA included gender, majors, course registered in at the time of this study, age, and years in college. MANOVA results show that course had a major influence on students' responses to test items identified under factors A1, A3, B1, and C2. Table 15 provides the MANOVA results.
Table 15: Results of the MANOVA of Students' Responses to the NOBKS Questionnaire.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor A1:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>33.14</td>
<td>14.42</td>
<td>2.29</td>
<td>0.13</td>
</tr>
<tr>
<td>Majors</td>
<td>4</td>
<td>16.32</td>
<td>14.56</td>
<td>1.12</td>
<td>0.35</td>
</tr>
<tr>
<td>Course</td>
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<td>16.79</td>
<td>12.86</td>
<td>6.25</td>
<td>0.01*</td>
</tr>
<tr>
<td>Years-IC</td>
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<td>5.79</td>
<td>14.04</td>
<td>0.14</td>
<td>0.74</td>
</tr>
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<td>26.82</td>
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</tr>
<tr>
<td><strong>Factor A2:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>20.06</td>
<td>7.17</td>
<td>0.07</td>
<td>0.93</td>
</tr>
<tr>
<td>Majors</td>
<td>4</td>
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<td>1.19</td>
<td>2.03</td>
<td>0.09</td>
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<tr>
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<td>6.37</td>
<td>2.36</td>
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<td><strong>Factor A3:</strong></td>
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<td><strong>Factor B1:</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Gender</td>
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<td>13.67</td>
<td>1.73</td>
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<tr>
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<tr>
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<td>12.46</td>
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<tr>
<td>Years-IC</td>
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<td>18.12</td>
<td>13.26</td>
<td>1.36</td>
<td>0.25</td>
</tr>
<tr>
<td>Age</td>
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<td>22.18</td>
<td>13.74</td>
<td>1.61</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Where DF = Degrees of freedom, SS = Sums of squares, MS = Mean squares, Years-IC = Years in college, *Significant influence of students' characteristics on their students' responses set at p < 0.01).
Table 15 (continued)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
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<th>p-value</th>
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<td>0.53</td>
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<td><strong>Factor C2:</strong></td>
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<td>10.70</td>
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<td>17.92</td>
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</table>

Where DF = Degrees of freedom, SS = Sums of squares, MS = Mean squares, Years-IC = Years in college, * Significant influence of students' characteristics on their students' responses set at p < 0.01.

To reiterate the constructs these factors represented, factor A1 represented students' understanding of scientific methods. Factor A3 represented students' understanding of the basis, scope, and limits of biological knowledge. Factor B1 represented students' understanding of natural selection and related concepts. Factor C2 represented students' understanding of evolutionary models in understanding homologous and analogous structural
features among living organisms. Since only data from students’ posttest responses to the NOBKS questionnaire were used in this study, the results of the MANOVA in Table 15 are all the results between-group comparisons. In other words, there are no within-group comparisons shown in Table 15 because students’ pretest responses were not compared with posttest responses to the NOBKS questionnaire. The statistically significant influence of course on factors A1, A3, B1, and C2 may imply that students in the advanced zoology course performed better than students in the introductory biology course in their responses to the test items that loaded on those four factors.

In fact, separate factor analysis result of introductory biology and zoology students’ responses during preliminary factor analysis confirmed this very finding. Factor correlation coefficients (loadings) from introductory biology students’ responses were generally lower than those of advanced zoology students. The above MANOVA findings may also imply that there were more correct responses to test items identified under factors A1, A3, B1, and C2 among zoology students’ responses than among introductory biology students’ responses.

In other words, this study shows that the advanced zoology students held more-scientifically-acceptable conceptions about scientific methods (A1) beliefs about the basis of biological knowledge, origin of life, and biological processes (A2), importance of evolution in biological processes (B1), and evolutionary models, homologous and analogous anatomical features (C2) than the introductory biology students. The influence of the advanced zoology
course on students' responses to the above factors may be a result of several confounded factors. Firstly, may be due to the fact that the advanced zoology students had taken more biology courses including those containing evolutionary concepts than the introductory biology students. Secondly, it may be the result of the instructional materials used by the advanced zoology course instructor to reinforce students' understanding. In fact, ZOOL 3152 course had a laboratory section which complemented the lectures, whereas the introductory biology course consisted of lectures only.

Even though the findings of this study are from a very focused examination of college students' understanding of the evolutionary nature of biological knowledge, the implications of the findings are beyond students' understanding of evolutionary concepts passe'. Findings of this study show that laboratory activities and comprehensive discussions that apply the theory of evolution to everyday situations reinforce students understanding of the nature of biological knowledge. Endler (1986) found that students' understanding of natural selection and related concepts were reinforced among his students by laboratory projects and observations of nature during field trips.

Thirdly, in conceptual change terms, these MANOVA findings suggest that students in the advanced zoology class possessed a greater array of concepts in their conceptual ecology, and were more willing to use those concepts in their explanations than those in the introductory biology course. This may also imply indirectly that there was more conceptual change among the advanced zoology students than among the introductory biology students.
Zoology students, therefore, used more logical and radical reasoning and explanatory strategies, and evidence to support their claims than the introductory biology students. Qualitative results of students' verbal and written interview responses are provided at the end of this chapter.

MANOVA results showed no influence of students' gender, major, years in college or age on all the seven factors extracted from students' responses, implying that students' gender, major, years in college or age do not influence their conceptions related to the nature of biological knowledge. In view of lack of similar studies which have quantitatively assessed students' understanding of evolution in relation to other biological concepts and general nature of biological knowledge, it is suggested that future studies be conducted to probe further the influence of course on the students' conceptions identified in this study. Such a study, particularly, one in which an introductory level and an advanced level biology are being taught by same instructor would eliminate instructor effects and provide more insights into students' learning strategies and conceptions related to the nature of biological knowledge.

**Summary of Quantitative Findings**

From the descriptive statistics results, the correct students' agreement responses for each test items are indicated on the table using the symbols "hc" for correct high agreement, "mc" for correct moderate agreement, and "lc" for correct low agreement responses. Incorrect students' responses to each test item are indicated using the symbols "mi" for incorrect moderate agreement, and "li" for incorrect low agreement responses as shown in Table 16.
Table 16: Summary of the Descriptive Statistics, Factor Analysis, and Statistically Significant MANOVA Results of Students' Responses to the 60-item NOBKS Questionnaire

<table>
<thead>
<tr>
<th>Part of NOBKS</th>
<th>Factor</th>
<th>Test items</th>
<th>Constructs Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1©</td>
<td>5hc, 6hc, 7hc, 8hc, 9hc, 10hc, 11hc, and 19mi</td>
<td>Understanding of scientific methods.</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>1li, 12li, 13li, 14li, 15li, 16li, 17li, and 18li</td>
<td>Beliefs about the basis of biological knowledge, origin of life &amp; biological processes.</td>
<td></td>
</tr>
<tr>
<td>A3©</td>
<td>2lc, 3lc, 4lc, and 20lc</td>
<td>Understanding of the scope and limitations of biological knowledge.</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>26hc, 27hc, 28mc, 30lc, 31*lc, 32lc, 35hc, 36mc, 37mc, 39hc, and 40mc</td>
<td>Understanding of natural selection and related concepts.</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>41hc, 42mc, 43*lc, 44mc, 46hc, 49hc, 50mc, 53hc, 54hc, 57hc, 59hc, and 60hc</td>
<td>The role of evolutionary models in understanding biological classification.</td>
<td></td>
</tr>
<tr>
<td>C2©</td>
<td>45mi, 47li, 48li, 51li, 52li, 55li, 56li, and 58li</td>
<td>The role of evolutionary models in understanding homologous &amp; analogous features.</td>
<td></td>
</tr>
</tbody>
</table>

Where hc = high correct agreement, mc = moderate correct agreement, mi = moderate incorrect agreement, lc = low correct agreement, and li = low incorrect agreement, © = influence of course.
It is assumed for purposes of discussions that presence of greater numbers of correct agreement responses either in the form of "hc", "mc", or "lc" associated with test items that make up a given factor is suggestive of scientifically-acceptable conceptions among students. Table 16 provides a summary of all the quantitative findings with the exception of Pearson's correlation results. The latter are provided immediately following the results summarized in the table. Similarly, it is assumed that presence of greater numbers of incorrect agreement responses either in the form of "mi", or "li" associated with test items that make up a given factor is suggestive of prescientific conceptions among students. The researcher should also note that because factor analysis complemented descriptive statistical analysis, some of the test items such as 31* and 43* (shown with an asterisk in Table 16) loaded with factors containing test items which had similar set of constructs on the factor analysis matrix.

In this way, factor analysis cross-checked the validity of the descriptive statistical analysis. The clustering of test items on all the 60 test items was conducted by the General Linear Model of SAS (SAS, 1996) at a Cronbach alpha reliability coefficient of 0.730 for the entire instrument, 0.761 for Part A, 0.700 for Part B and 0.731 for Part C of the NOBKS questionnaire. Statistically significant influence of course on students' conceptions are indicated by using the symbol "©" in the table.

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Summary of Quantitative Findings for Primary Research Question 1

Primary research question 1 is: "What conceptions related to the general nature of biological knowledge do college introductory biology and zoology students hold?". Findings from analyses of students' responses to Part A of the NOBKS questionnaire provided answers to this question. Descriptive statistical analysis showed that at least 80% of college students hold scientifically-acceptable understanding of the scientific methods, represented by factor A1 in Table 16.

Secondly, analysis of Part A of the NOBKS questionnaire showed that college students hold several prescientific beliefs and conceptions about the basis of biological knowledge, origin of life, and nature of change in biological processes. These findings are represented as factor A2. Students' responses to the test items associated with these prescientific conceptions are in the incorrect low agreement category, shown with superscript symbol "li". Descriptive analysis results for Part A of the NOBKS also show that few college students have scientifically-correct understanding of the scope and limits of biological knowledge. This conception is indicated by factor A3 in Table 16. Students' responses were in correct low agreement category. Test items included test items 2, 3, and 4. The study showed that only half (51%) of the students knew biological knowledge provides answers to most questions about living organisms. Table 17 provides a summary of the percentages of college students identified with such prescientific beliefs and conceptions.
Table 17: Prescientific Beliefs and Conceptions about the Origin and Nature of Biological Processes Identified among College Biology and Zoology Students.

<table>
<thead>
<tr>
<th>Factor A2 test items</th>
<th>Prescientific Conception</th>
<th>Percentage of students with preconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test item 1</td>
<td>Biology not grounded in nature</td>
<td>19%</td>
</tr>
<tr>
<td>Test item 12</td>
<td>Creationist conceptions about the origin of life</td>
<td>26%</td>
</tr>
<tr>
<td>Test item 13</td>
<td>Teleological conception about nature of change in biological processes</td>
<td>50%</td>
</tr>
<tr>
<td>Test item 14</td>
<td>Constitutive non-reductionist conception about the composition of living things</td>
<td>33%</td>
</tr>
<tr>
<td>Test item 15</td>
<td>Nonreductionist conception about influence of nature on living things</td>
<td>31%</td>
</tr>
<tr>
<td>Test item 16</td>
<td>Vitalist conception that a “mystic” non-measurable force exists in living things.</td>
<td>56%</td>
</tr>
<tr>
<td>Test item 17</td>
<td>Nonemmegentist conception</td>
<td>58%</td>
</tr>
<tr>
<td>Test item 18</td>
<td>Chance plays no role in biological processes</td>
<td>36%</td>
</tr>
</tbody>
</table>
About 36% of the students responded that biology cannot answer questions about the meaning of life. Only 17% of the students responded that biology cannot answer questions about human values. These students did not know that value-rated issues are often difficult to find empirical evidence for. They also did not know that issues that are outside the realms of nature are also outside the realms of science. Students' interview responses to questions in Parts 2 and 3 of the interview complemented the above results.

**Summary of Quantitative Findings for Primary Research Question 2**

Analysis of students' responses to Part B of the NOBKS provided answers to primary research question 2: "What conceptions related to knowledge of evolutionary biology do college biology and zoology hold?" Table 16 provided earlier provided a summary of the descriptive and factor analysis results of students' responses including those for Part B of the NOBKS questionnaire.

Descriptive results showed that many (at least 59%) of the students who participated in this study did not understand the importance and consequences of evolution (factor B1). Test items under this factor are in the low incorrect agreement response category of Part B in Table 16 shown earlier. However, descriptive results also showed that most (80-100%) of the students had encountered natural selection and related evolutionary concepts (factor B2) in their biology courses. Students' responses to questions in Parts 4, 5, and 6 of the interviews complemented the above findings.
Summary of Quantitative Findings for Primary Research Question 3

Analysis of students’ responses to Part C of the NOBKS provided answers to primary research question 3: "What conceptions related to knowledge of homologous and analogous anatomical features do biology do college biology and zoology hold? The summary of descriptive and factor analysis results are also provided in Table 16. Descriptive showed that a moderate number (60-80%) of introductory biology and most (80-100%) of zoology students who participated in this study understood biological classification as based on understanding similarities and differences among organisms.

However, more zoology students understood the usefulness of divergent and convergent evolutionary models for studying and making inferences about the structural similarities and differences observed among living organisms. Zoology students also used knowledge of evolution to explain the process of speciation among living organisms during student interviews. Part 7, 8 and 9 of the qualitative results show students responses that complemented the above quantitative results.

Summary of Quantitative Findings for Secondary Research Question 1

Secondary research question 1: “How do students' conceptions related to the general nature of biological knowledge relate to their knowledge of evolutionary biology, and knowledge of homologous, and analogous anatomical features?” Pearson's correlation analysis of students' responses to Parts A, B, and C of the NOBKS provided answers to this question.
Pearson's correlation results showed that students who do not understand the importance of the theory of evolution by natural selection (factor B1) hold prescientific conceptions about the origin and nature of change in living organism (factor A3). These prescientific conceptions have been identified as creationism, vitalism, nonreductionism and nonemergerntism. Similarly, students who hold prescientific beliefs or conceptions (factor A3) did not understand the importance of evolutionary models (factor C2) in understanding similarities (such as homologous features) and differences (such as analogous features) that are observed among living organisms.

**Summary of Quantitative Findings for Secondary Research Question 2.**

Secondary Research Question 2 is: "Do course, students' age, gender, major or years in college influence students' conceptions related to the nature of biological knowledge?" Multivariate analysis of variance (MANOVA) was used to answer this research question. MANOVA results showed the course students were registered in was the only factor that showed statistically significant influence on students' responses about the nature of biological knowledge.

The influence of course as observed, particularly, among factors A1, A3, B1 and C2. These factors represented students' conceptions related to scientific methods (factor A1), students' understanding of the scope and limits of biological knowledge (factor A3), students' understanding of the importance and consequences of evolution (factor B1), and students' understanding of evolutionary models, namely divergent and convergent models, in
understanding anatomical similarities and differences among living organisms. The remaining students' characteristics, namely, gender, major, years in college, and age had no influence on the above factors and all the other factors identified in this study. Qualitative results which are provided in the following section complement the above quantitative findings.

**Qualitative Results**

In this section, qualitative results are presented in the order in which they answer the research questions. Students' interview responses to the test items on the NOBKS questionnaire and related specific interview questions responses are provided together. As described earlier in Chapter 3, twenty volunteer students, all from Louisiana State University Baton Rouge campus, were interviewed. Ten of the 20 interviewees were registered in the introductory biology course and the other ten were registered in the zoology course.

In terms of interviewees' gender, ten of the interviewees were females and ten were males. With respect to their majors and the colleges they belonged to, 18 of the interviewees were from the College of Basic Science, 1 was from the College of Education, and 1 interviewee was from the school of Veterinary medicine. Of the 18 interviewees from the College of Basic Sciences 17 were majoring in various preprofessional and professional programs in the Department of Biological Sciences and the remaining interviewee, specifically, Z18 was a geology major.

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Table 18: Description and Content Analysis of Interviewees’ Biological Knowledge and Family Backgrounds

<table>
<thead>
<tr>
<th>Research Code</th>
<th>Gender</th>
<th>Age (YIC)</th>
<th>H-S(College)</th>
<th>BIOL-courses</th>
<th>Major (College)</th>
<th>Scientist in family</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>F</td>
<td>20 (1)</td>
<td></td>
<td>1 (1)</td>
<td>KINE (EDU)</td>
<td>NO</td>
</tr>
<tr>
<td>B6</td>
<td>F</td>
<td>19 (1)</td>
<td></td>
<td>1 (1)</td>
<td>ZOOL (BSC)</td>
<td>NO</td>
</tr>
<tr>
<td>B8</td>
<td>F</td>
<td>19 (1)</td>
<td></td>
<td>1 (1)</td>
<td>NURS (BSC)</td>
<td>NO</td>
</tr>
<tr>
<td>B12</td>
<td>M</td>
<td>20 (2)</td>
<td></td>
<td>2 (2)</td>
<td>PREM (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>B21</td>
<td>F</td>
<td>22 (2)</td>
<td></td>
<td>2 (2)</td>
<td>PREV (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>B55</td>
<td>M</td>
<td>22 (2)</td>
<td></td>
<td>2 (2)</td>
<td>MICR (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>B56</td>
<td>M</td>
<td>25 (3)</td>
<td></td>
<td>2 (2)</td>
<td>MICR (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>B75</td>
<td>M</td>
<td>27 (5)</td>
<td></td>
<td>2 (&gt;5)</td>
<td>MICR (SVM)</td>
<td>YES</td>
</tr>
<tr>
<td>B100</td>
<td>M</td>
<td>19 (1)</td>
<td></td>
<td>1 (3)</td>
<td>MICR (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>B121</td>
<td>M</td>
<td>20 (1)</td>
<td></td>
<td>1 (1)</td>
<td>KINE (EDU)</td>
<td>NO</td>
</tr>
<tr>
<td>Z1</td>
<td>F</td>
<td>24 (3)</td>
<td></td>
<td>0 (5)</td>
<td>PRED (BSC)</td>
<td>NO</td>
</tr>
<tr>
<td>Z3</td>
<td>M</td>
<td>22 (3)</td>
<td></td>
<td>2 (4)</td>
<td>ZOOL (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>Z8</td>
<td>F</td>
<td>23 (4)</td>
<td></td>
<td>1 (4)</td>
<td>ZOOL (BSC)</td>
<td>YES</td>
</tr>
</tbody>
</table>

Where F= female, M= male, YIC= Years in college, H-S=High school, BIOL-courses = Biology courses, BSC = College of Basic Sciences, EDU = College of Education, SVM = School of Veterinary Medicine, KINE = Kinesiology, MICR=Microbiology, PRED = Predental, PREM = Premedical, PREV = Preveterinary, NURS = Nursing, NEUR = Neurobiology, and ZOOL=Zoology major.
Table 18 (continued)

<table>
<thead>
<tr>
<th>Z9</th>
<th>M</th>
<th>24 (5)</th>
<th>2 (&gt;5)</th>
<th>NEUR (BSC)</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z10</td>
<td>F</td>
<td>23 (3)</td>
<td>2 (5)</td>
<td>MICR (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>Z11</td>
<td>F</td>
<td>22 (3)</td>
<td>2 (4)</td>
<td>MICRO (BSC)</td>
<td>NO</td>
</tr>
<tr>
<td>Z12</td>
<td>M</td>
<td>23 (4)</td>
<td>1 (4)</td>
<td>PRED (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>Z18</td>
<td>M</td>
<td>22 (3)</td>
<td>1 (4)</td>
<td>GEOL (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>Z19</td>
<td>F</td>
<td>23 (4)</td>
<td>2 (&gt;5)</td>
<td>PREM (BSC)</td>
<td>YES</td>
</tr>
<tr>
<td>Z20</td>
<td>F</td>
<td>25 (4)</td>
<td>2 (&gt;5)</td>
<td>PREV (BSC)</td>
<td>YES</td>
</tr>
</tbody>
</table>

Where F= female, M= male, YIC= Years in college, H-S=High school, BIOL-courses = Biology courses, BSC = College of Basic Sciences, EDU = College of Education, SVM = School of Veterinary Medicine, KINE = Kinesiology, MICR=Microbiology, PRED = Predental, PREM = Premedical, PREV = Preveterinary, NURS = Nursing, NEUR = Neurobiology, and ZOOL=Zoology major.

Table 18 also includes information on interviewees gender, years in college, number of biology courses taken or completed in high school and college, and whether or not they came from families in which at least one parent is a scientist.

Majors of interviewees from the Department of Biological Sciences included those of zoology, microbiology, nursing, predental, premedical, and preveterinary programs. Interviewee B1 who was the only one from the College of Education was a kinesiology major. Interviewee B75 who was also the only one from the School of Veterinary Medicine, was microbiology major.
Part 1: Students' Biology and Family Backgrounds

Below are further descriptions of the interviewees following their responses to questions in Part 1 of the interview. These responses also confirmed the information each student had provided on the student release form each had signed prior to participation in this study.

Introductory Biology Interviewees

All introductory biology interviewees were identified by the same research codes they had been assigned during questionnaire administration. These research codes consisted of numbers beginning with the letter B. Among the 10 interviewees from the introductory biology course, four of them, namely, B1, B6, B8, and B12, were freshmen at the time of this study. Each of them had taken only one biology course in high school and college. BIOL 1201 was their first college level biology.

The other common characteristic they shared was that each of them came from families with no parents who were scientists. In terms of their majors and the college they were in at Louisiana State University. Interviewee B1 was a kinesiology major in the College of Education. Interviewee B6 was a zoology major in the College of Basic Sciences. Interviewee B8 was a nursing student in the College of Basic sciences. Interviewee B12 was in the premedical program in the College of Basic Sciences.

The remaining six introductory biology students who came from families in which at least one parent was a basic or an applied scientist. Interviewees B21, B55, and 56 were all second year college students. Each of them had
taken 2 biology courses in high school and two biology courses in college. Interviewees B100 and B121 were both first-year students. Interviewee B100 on had taken 1 high school biology and 2 college level biology courses before the BIOL 1201 he was taking at the time of this study. Interviewee B121 had taken one biology course in high school and BIOL1201 was his first college level biology. In terms of their majors, interviewee B21 was in the preveterinary program at the College of Basic Sciences.

Interviewees B55 and B56 were second and third year microbiology majors in the College of Basic Sciences. Interviewee B75 was also a microbiology major at the school of Veterinary Medicine and had completed a bachelor of science degree from Texas Agricultural and Mechanization University and College (Texas A & M). At Louisiana State University interviewee B75 was already in the veterinary program but had been asked to take BIOL 1201 by his microbiology supervisor.

Zoology Interviewees

All zoology interviewees were also identified during interviews by the same research codes numbers each had been assigned during questionnaire administration. All zoology interviewee were identified with numbers beginning with the letter Z. With the exception of Z9 and Z11 all the 10 zoology interviewees came from families with at least one scientist. Interviewee Z1 was 24 year old female and junior in the predental program in the College of Basic Sciences. Interviewee Z3 was a 22 year-old male and junior majoring in zoology in the College of Basic Sciences.
Interviewee Z8 was a 23 year-old female and senior majoring in zoology and in the College of Basic Sciences. Interviewee Z18 was a 22 year-old male and geology major in the College of Basic Science. Interviewee Z20 was a 25 year-old female in the preveterinary program in the College of Basic Sciences. Individual interviewees' interview responses are provided beginning in Part 2 of the qualitative results.

Part 2: Students' Conceptions of Science and Biology

The responses provided here are from interviewees in response to questions in Part 2 of the student interview questions (see Appendix E). Seventeen of the 20 interviewees from both biology and zoology class defined science as a systematic study of nature and biology as the study of the living organism currently known to exist in nature. Seven of those who provided accurate definitions of science and nature were from the biology class and the other 10 were all the zoology interviewees. Some of the interviewees provided elaborate explanations of science including descriptions of the scientific methods used to study natural phenomena such as observations, hypothesis testing, data collection and analysis, and making inferences.

The correct interview responses of the 7 out of 10 biology and all 10 zoology about the definitions of science, biology, and how scientific knowledge is derived are consistent with the descriptive analysis of students' responses to test items 5, 6, 7, 8, 9, 10, and 11 in which at least 80% of the students were found to have provided correct agreement responses to those test items. However, students' definitions of biology varied even among those who had

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provided correct definitions of science. For instance, three of the 10 interviewees biology interviewees added phrases that suggested they did not completely understand the scope and limits of biology. Interviewee B1 wondered if all knowledge of biology is derived from nature and thought theories used in biology are not as concrete as those used in the physical science. Interviewee B6 provided a definition of science which included study of both the seen and unseen. His explanation implied that he thinks biologists sometimes "believe in things they cannot see". Interviewee B12 thought biology is inferior to the physical sciences.

Interviewees B1 and B12 represented the 20% of the students in this study who incorrectly agreed with the statement in test item 1 of the NOBKS questionnaire that "biological knowledge is not grounded in the natural world". Their responses implied that biological knowledge included knowledge from unnatural sources. Below are various interviewees' responses and descriptions of science and biology provided by both biology and zoology interviewees. Interviewees' responses which suggest existence of prescientific conceptions in students' understanding are indicated with an asterisk (*).

*B1: "Science studies nature...(pause)... or is supposed to study nature. Yes, that's what I have been taught since kindergarten. But sometimes I wonder if all knowledge of biology is derived from natural studies. I think knowledge of nature alone is not sufficient to understand the whole living organism. Besides, the theories of biology are not concrete like the laws of physics or principles in chemistry".

B8: "Science is the study of things we see as well as those we can't see but can use scientific instruments to collect data which we can use to infer their characteristics".

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"Science deals with the study of nature and everything in it. Natural laws determine what we study and see, but biology is only guided by theories, not laws. That kind of makes biology a little bit inferior to physics and chemistry. except when we need to know how the human body works.

Science encompasses the study of all aspects of nature, both what we can see with the naked eye and what we cannot see but are part of nature”.

Science studies nature. Biology to me is the most important kind of knowledge about the natural world, because it allows us to understand more about ourselves and other organisms sharing the environment or natural world with us”.

"Science deals with the study of things we can observe and deals with natural processes. Biology is a life science compared to the physical sciences which deal with natural objects and the laws that govern actions of those objects".

"Science is the study of natural processes and phenomena that adhere to natural laws and theories. Science is different from the other subjects because there are set rules that can only be broken down through exceptions”.

“Science deals with things we can see or observe in nature. It is more interesting but more difficult than the other subject. Biology deals less with laws and more with changes that are unpredictable. Since biology studies living organisms and living organisms are part of nature and sometimes depend on the physical world for nutrients, then biology is grounded in the natural world and helps us to study how and why living organisms are interdependent and dependent on the physical world..pause.. yes, science is useful for understanding why both living and non-living things behave”.

“Science studies different aspects nature and biology deals directly with living things”.

“Science is the study of living and non-living things in nature".
Z9: "Science is the process of taking observable phenomena and integrating the knowledge from them into large interrelated body of knowledge via testable hypotheses".

Z11: "Science is the study of natural phenomena only. Other subjects deal with things outside nature, things like values, which we can only believe in, but are not tangible. Biology encompasses all the aspects of life including its chemistry".

Z18: "Science as a collection of knowledge about and interpretation of scientific data. Empirical evidence is very important in science because knowledge is falsifiable based on observations. Biology is different from other sciences because the systems it studies are so complex that you cannot establish general laws about them".

Z19: "Science is the exploration of our environment through research and experimentation. Biology is more complex than other sciences because we have to apply knowledge of both chemistry and physics in biology classes. This is not usually easy to do".

Z20: "Science studies nature systematically using the scientific method and evidence from data collected from nature studies. Biology studies the structure and function of living things".

Interviewees B1, B6, and B12 did not only suggest the lack of understanding of the scope of biological knowledge as being limited to nature, but also suggested existence of vitalistic conceptions among these students' conceptual framework.

Part 3 of the student interview results provided more insight of the interviewees' conceptions and beliefs about the nature of biological processes. It also provided more insight on how students prescientific beliefs and conceptions influence their "grand schematic understanding" of the nature of science, particularly, from a biological knowledge perspective.
Part 3: Students' Understanding and Beliefs about the Origin and Nature of Change in Biological Processes

The responses provided here are from interviewees in response to questions in Part 3 of the student interview questions (see Appendix E). Analysis of students' responses to test items 12, 13, 14, 15, 16, and 17 of the NOBKS questionnaire indicated that a few had creationist (12), vitalist and teleological (13), constitutive nonreductionist (14), nonreductionist (15), vitalist (16), and nonemergentist (17) viewpoints. Three out of 10 interviewees from the introductory class, namely, B1, B12, and B100 and two from the zoology class, namely, Z3 and Z4 verbally agreed with the statement in test item 12. Below are excerpts from transcripts of their audiotaped responses. Interviewees' excerpts that suggest existence of prescientific conceptions in students' understanding are indicated with an asterisk (*).

*B1: "All organisms were created by God,...pause... and God controls how they have changed over subsequent generations, and whether they die or multiply due to adverse environmental conditions like floods or other natural disasters".

*B12: "To me, I think evolution may have taken place in other species, probably, in bacteria or some lower organisms, but not in humans. I have always had a problem seeing the relevance of evolution to humans. I don't think and cannot see how we have evolved". As for #13 I agree because if evolution has taken place it must be for the good of the organisms. Why else would anyone or anything want to change".

*B100: "I know I have been taught that the big bang" as a disaster is responsible for the origin of life, but I am not certain if it really occurred, and if it is not just a"theory" or "blind guess" that is being used by scientists to explain the biodiversity we see today"
*Z3: “I think living organisms, particularly humans, were created by God since they carry out processes that make them very unique from other living things and from non-living objects. The more I see the complexity of the anatomical structures I am dissecting, the more I doubt if evolution is really responsible for putting all those structures together in the right place for every organism”.

*Z4: “Yes I think living organisms were created by God. But I also think they have changed and evolved over the years so that they no longer look like the ancestral organisms. Yes, they are, but these atoms and molecules are only part of the big picture or living things. I mean, living cells tend to behave differently from nonliving objects.”

Explanations provided by Z3 and Z4 show that students hold not only creationist view points, but also typological and teleological mode of reasoning about evolutionary change. Z3’s response shows some element of anthropocentricism, in which he places all humans above everything else in nature. Z4’s explanation shows that students may hold dual conceptions about the origin and evolutionary process. The above explanations, particularly, among interviewees who had provided correct explanations of what science and biology is, suggest that holding vitalistic creationist, or teleological explanations do not influence students understanding of the scientific process.

Part 4: Students' Understanding of Mutation and Natural Selection

Results of Interview 4 questions complemented students' responses to test items 21, 22, 23, 24, 24, 29, 30, 39, 35, and 40 of Part B of the NOBKS questionnaire. When interviewees were asked to explain the mechanism of evolution by natural selection and how natural selection differs from genetic mutations, students' responses ranged from lack of differentiation of the two.
processes, to prescientific explanations. Prescientific explanations included Lamarckian, anthropomorphic, and teleological explanation responses. Interviewees B1, B6, B12, B100 and B121 identified both natural selection and mutations as similar processes. Three interviewees from the introductory biology class explained that mutations and natural selection are distinguishable because the former takes place in bacteria and lower organisms only, while the latter takes occurs only in larger organisms.

Students' responses to the levels at which the two processes occur were also confusing. One-half of introductory biology interviewees and two advanced zoology interviewees, namely, Z3 and Z11 provided an explanations which showed that they viewed natural selection as a beneficial process "always" to the organisms involved. The following are excerpts of interviewees verbal responses. Interviewees written interview responses are summarized later in Figures 18 and 19. Excerpts from interviewees verbal responses suggest existence of prescientific conceptions and lack of integrated knowledge about genetic mutation and natural selection among students. Excerpts showing presence of prescientific conceptions are indicated with an asterisk (*).

*B1:  "Mutation is very similar to natural selection because it is a change in the organisms caused by disasters in the environment".

*B6:  "Both Mutation and natural selection occur at cellular and tissue level. After that we cannot see any natural selection, we can only assume that it is there, we can't really see it.

B8:   "Evolution occurs to give organism more chance of survival. Individuals have better chance to reproduce and mutate and pass on mutated genes to their offspring".

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"B12: "Both mutation and natural selection as processes which occur at all levels of organization, particularly... (pause)... in bacteria".

B75: "Natural selection is a process whereby one characteristic give a certain individual an advantage and better chance to reproduce viable offspring to carry on their genes and traits".

"B100: "Both mutation and natural selection occur at all levels of biological organization, and their influence are observed in the individual organisms. Natural selection is a process by which some organisms have survived and others simply died. Bacteria and viruses always undergo mutations so they are hard to kill even with strong medicine. However, I doubt if natural selection is responsible for that! I think it is only genetic mutations one after another... (pause)... very rapid mutations!

"B121: "Mutations are common among viruses and bacteria because they multiply very fast. Natural selection needs slow growth rate so if it occurs it is usually in plants and animals only... (pause)... I mean natural selection is supposed to be a slow process... (pause)... so it should be rare in bacteria because they grow very fast".

Z1: "Evolution occurs through the process of natural selection. Natural selection is a process in which organisms become better adapted in their environment and produce offsprings that are more resistant to environmental hazards. The organisms develop behavior that make them more fit... (pause)... and better adapted to the environment. Mutation and natural selection are both changes occurring within the cells of an organism".

"Z3: "I think... (pause)... natural selection always gives survivors advantage and they will always live better in every new generation. Natural selection is, it is always advantageous or leads to betterment of the survivors in response to the change in the environment".

Z4: "Natural selection occurs when there is individual variation and selective pressure from the environment".

Z8: "During natural selection, some organisms have genetic characteristics that allow them to adapt better to their environment so that they survive better than others in the same environment".
Z9: "Natural selection is a kind of adaptation which allows an organism to favorably respond to selective pressures of a particular environment. But mutation has a strict genetic context".

*Z11: "Natural selection is the process by which particular traits are selected in organisms and this selection makes their offsprings always better than the previous generation. The children of those that survive are always better off than their parents"

Using content analysis technique and symbolic graphical representations as recommended by Tufte (1992), the researcher has represented students' responses about the levels at which genetic mutation and natural selection occur in Figure 18 for introductory biology students' responses and Figure 19 for the advanced zoology students' responses. Each of the 10 interviewee's responses from each class are represented separately in order to determine students' understanding of the emergent nature of biological knowledge as well as their understanding of biological hierarchy. This representation also provided insight about which interviewees had incorrectly or correctly responded to NOBKS test items and standardized interview questions related to natural selection and genetic mutations. Content qualitative content analysis results of introductory biology interviewees responses about the levels of organization at which genetic mutation and natural selection occur is provided first in Figure 18. Five of the 10 introductory biology interviewees, namely, B1, B6, B12, B100 and B121 could not differentiate genetic mutations from natural selection. Moreover, all the 10 introductory biology interviewees incorrectly responded that the influence of natural selection is observed at individual organismic level.
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\[ \text{Mutation plus Natural Selection} \]

\[ \text{Mutation only} \]

\[ \text{Natural selection only} \]

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Where MOL = Molecular level, CEL = cellular level, TIS = Tissue level, ORG = Organ system level, IND = individual organism level, COM = Community or ecosystem level, BIOS = Biosphere or Ecosphere level.

Figure 18: Content Analysis Results of Introductory Biology Students' Responses Related to Levels of Biological Organization at which Genetic Mutations and Natural Selection Occur in Living Organisms.
\( \bigcirc \) = Mutation plus Natural Selection
\( \bigcirc \) = Mutation only
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Where MOL = Molecular level, CEL = cellular level, TIS = Tissue level, ORG = Organ system level, IND = individual organism level, COM = Community or ecosystem level, BIOS = Biosphere or Ecosphere level.

Figure 19: Content Analysis Results of Advanced Zoology Students' Responses Related to Levels of Biological Organization at which Genetic Mutations and Natural Selection Occur in Living Organisms.
Interviewees B1, B6, B12, and B121 could not distinguish mutation from natural selection. These three interviewees believed that mutations only occur in lower organisms and natural selection only occurs in higher order organisms. According to these students' explanations, they have been taught that natural selection is a slow gradual process. Using that type of reasoning it was a process too slow to occur in organisms higher on the classification system than bacteria. Furthermore, all biology interviewees indicated in their written interview responses that the consequences of both mutation and natural selection are observed at the individual organism level. These results imply that biology interviewees did not have an integrated knowledge of the complementary nature of micro- and macroevolutionary processes as zoology interviewees did.

Most zoology interviewees correctly identified natural selection as taking place at the population level. However, interviewees Z3 and Z11 could not distinguish between the levels at which mutation and natural selection take place. In addition some of the zoology interviewees, namely, Z1, Z4, Z11, Z19, and Z20 also incorrectly included the individual organisms levels in addition to the population levels as the levels at which natural selection is observable. These interviewees' responses suggest that students' explanations for natural selection are related to the manner in which evolutionary concepts are presented to them during instruction.
Part 5: Students’ Understanding of Mutations and Natural Selection as Proximate and Ultimate Adaptive Processes

Interviewees’ responses in Part 5 of the student interview further confirmed students’ difficulties distinguishing mutations from natural selection. Mosquito populations sprayed with DDT insecticide on an isolated island was used as example. Some interviewees correctly predicted that both genetic mutation and natural selection were responsible for the changing numbers of mosquitoes as the summer progressed.

However, while explaining natural selection, the statements in interviewee B1’s explanations indicated some elements of Lamarckianism. B1 explained that any adaptive behaviors learned by adult mosquitoes following the spraying of DDT in their environment would be transmitted to their offsprings. Most of the introductory biology students’ responses were similar to B1’s and most of zoology interviewee’s responses were similar to Z3’s verbal responses. Therefore only B1’s and Z’3 excerpts are provided below.

*B1: “For this population, mutation definitely was responsible for their survival. The more tolerant the mosquitoes became after mutating the better they became because the mutations helped them to dodge death.... (pause.... and I am sure if the spraying is continued the young mosquitoes would also become tolerant because they get this tolerance from the environment”.

Z1: “The mosquitoes became tolerant to the insecticide being sprayed because of both genetic mutation and natural selection. There were also new births by the tolerant population so that resistance must have been passed on to their offsprings, I mean, through the genes....(pause)...during reproduction”.

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When asked about the role of variation in the survival of these mosquitoes most zoology students correctly associated variation with genetic mutation. However, many introductory biology students had compartmentalized knowledge and did not know that the genetic make of the organism that determine which organism are selected for or against by environmental selection pressure. Below ia an excerpt of an incorrect responses provided by B6 which represented most of introductory biology students.

B6: “Variation occurred with mutation in mosquitoes which were not killed by the DDT. However, you cannot say that natural selection was helped by variation if at all it occurred because too many mosquitoes died in section II of the graph....pause... I mean, if natural selection had taken place then no mosquitoes would have died. If chance played any role it was not important ”.

The above response by interviewee B6 suggests that she had the conception that natural selection is “always” beneficial to organism. The above response which represents 7 out of 10 introductory biology interviewees’ responses plus those of advanced zoology students who held similar prescientific conceptions is consistent with the NOBKS questionnaire responses which showed that at least 75% of all students incorrectly responded during the questionnaire that natural selection “always” has beneficial consequences on the organisms involved.

On the other hand, most advanced zoology interviewees who provided correct responses about the role of variation and chance in the mosquito populations provided verbal responses similar to interviewee Z20’s response. An excerpt of interviewee Z20’s response is provided below.
Z20: “Variation is the trait that living organism have due to differences in their genetic make-up. This trait allows them to respond differently to environmental pressures. For the mosquitoes that were sprayed with DDT, variation allowed some adult mosquitoes which survived the spray to reproduce and pass on this genetic trait to their offspring. In the subsequent generations this trait can be selected for ... (pause) ... through evolution, and the mosquitoes in that generation will become resistant to DDT. Chance plays an important role in this selection process because some mosquitoes with the trait may still die”.

Advanced zoology students generally had a more integrated knowledge of mutation, natural selection, and the role of chance in the survival of living organisms than introductory biology students. Their responses also showed that they had a more integrated biological knowledge than introductory biology students. In literacy assessment terms, most zoology students were at least at the structural level of biological literacy while many in the introductory biology interviewees were at the nominal and function levels.

Part 6: Students' Understanding of Natural Selection and Biological “Fitness”

Among the interviewees who responded to this question, 8 out of the ten interviewees from the biology class, namely, B1, B6, B12, B55, B56, B100 and B121, and 2 out of the 10 interviewees from the advanced zoology class (Z3, and Z11) incorrectly selected Ben as the most fit and Sandy as the least fit. The reasoning these interviewees provided were similar to B1’s response given below. Most of them selected Ben because Ben was the largest in size. These interviewees equated “physical fitness” with “biological fitness”. Below is a typical excerpt from interviewee B1’s response.
"B1: “Ben is the most “biologically fit” because if you are not physically fit you cannot compete for anything. Physical fitness is more important than number of offspring fathered...pause.... that's why size is very important, even among athletes”. Sandy was least fit because he fathered cubs for only a short time and died early so... what was the use?”

It is important to note the anthropocentric analogy interviewee B1 made between the population of male lions and human athletes. This “analogous way of thinking” seemed to have reinforced her prescientific conceptions about biological fitness. Interviewees who correctly selected Sandy as most fit selected also correctly selected George as least fit and provided the reason that Sandy produced the greatest number of cubs per years. Secondly Sandy's cubs had the greatest survival rate. These interviewees included B21, B75, Z1, Z4, Z8, Z12, Z19 and Z20. Interviewee Z4's response is a typical example from this group of interviewees.

Z1: “Sandy seemed most “fit” in biological terms because he had more cubs that survive to adulthood every year. George was least fit, because he had the fewest number of cubs every year even though he died at a relatively older age compared to Sporty and Sandy. Looking at the table, I would consider fathering ability, and the average number of cubs surviving to adulthood per year as the most important criteria”.

The above interviewees' responses reveal that college students' interpretation of biological fitness varies a great deal depending on their understanding of the mechanism of natural selection. Interviewees who selected Sandy as the most “biologically fit” provided fathering ability, number of its cubs that survived to adulthood as the best criteria for determining
biological fitness. They explained that the age at which she died was only a secondary factor considering its ability to pass its genetic material to its offsprings.

**Part 7: Students' Understanding of Evolution and Speciation**

Most biology as well as zoology interviewees provided accurate and scientifically-acceptable explanations of a species of organisms. This is probably due to the fact that instructors in both classes spent considerable amounts of time to explain the species concept to both groups of students. Below are typical interview excerpts of explanations provided by interviewees from the introductory biology and advanced zoology classes. B75 and Z1 which were typical of the introductory biology and advanced zoology interviewees' responses.

**B75**: "A species is a geographically isolated group of organisms with individuals that are able to interbred and produce reproductively viable offsprings".

**Z1**: "A species is a group of organisms that can interbreed because they share similar genetic material, have similar behavior, and live in similar environment. Through intraspecific breeding, males and females of the same species exchange genetic material. Through the same process genetic traits and other morphological characteristics are passed on to the next generation".

When interviewees were presented with the question of the blind cave salamanders that may have evolved from sighted ancestors, eight if the ten interviewees from the introductory biology class and two of the interviewees from the zoology class held the opinion that the blind salamanders will continue to be blind even following several generations of living under a well-lit
environment, in say a research laboratory. These interviewees provided Lamarckian and teleological explanations about the evolution of blindness among the cave salamanders. They believed that the trait “blindness” evolved among cave salamanders because the sensory organs for sight progressively atrophied due to “disuse”. They also explained that after several generations these salamanders did not “need” sight so blindness was the “state of perfection” reached.

This prescientific reasoning about evolution by natural selection was also confirmed in their prediction. They predicted that blindness must have been the perfect state for these species of cave salamanders, therefore, moving them to a well-lit laboratory environment would have no influence on their evolution of sight. Below are excerpts from interviewee B6’s and other interviewees’ responses:

*B6: “If they have lost sight even because they did not need it, they may have also lost the ability to ever see again in the light... pause... so moving them to a well-lit environment will not help them in any way. After all, they lost the need to see a long time ago. These salamanders seem to have become adapted to darkness and their eyes probably underwent some kind of irreversible mutation”.

*Z1: “As the salamanders continued to live in dark caves, there was “no need” for eye sight so they became blind”.

Z8: “Because neurostimulation by light is important for the stimulation of retinal cells in order for them to see, then exposure of the existing features and retinal cells to light and may elicit a response to the light rays and cause firing of the optic nerves if the salamanders “need”to see in the well-lit environment”.

It is apparent from the above explanations that even though most students provided correct definitions of what a species is, they were unable to
explain the evolution of blindness (or sight) in terms of natural selection. Many students including graduate students in the advanced zoology class continued to provide Lamarckian responses. Interviewee Z8 provided a correct response at the proximate causation level but an incorrect Lamarckian response of "need" at the ultimate causation level.

Generally advanced zoology students who had spent over two years in college, had completed at least three biology courses prior to the comparative anatomy course they were taking during this study provided more elaborate and scientifically-correct explanations related to indeterminable outcomes of natural selection. Among the interviewees who provided scientifically-correct responses were interviewees B75, Z8, Z10, Z18, and Z20. According to interviewee B75, the salamanders could remain blind or gain sight in a well-lit environment after several generations. Both blindness and sight were possible outcomes of natural selection among these cave salamanders.

B75: "Yes, I think after several generations these blind salamanders will begin to see again if a mutation takes place that favors development of a trait for light stimulation of the retinal cell. After several generation of breeding and exchange of genetic material among those with the trait for sight, all the salamanders that are selected for under the well-lit environment will have sight in the presence of light".

The researcher provided the question on blind salamanders right before Part 8 of the interview in order to "prime" students to begin thinking about biological classification in evolutionary terms for the interview questions in Parts 8 and 9. Questions for Parts 8 and 9 are also provided in Appendix E. Because most introductory biology interviewees did not understand the evolutionary
history homologous and analogous anatomical features most of their responses for Part 8 and 9 were incomplete and have not been reported in this manuscript. Only advanced zoology students responses are included for the standardized interview questions that related to divergent and convergent evolutionary models. Both written as well as verbal explanations of zoology students' responses about the relationships among invertebrate and vertebrate species are provided in the subsequent sections.

**Part 8: Students' Understanding of Divergent Evolutionary Model**

Content analysis of advanced zoology students' responses to Part 8 of the standardized interview question and their explanations about the relationships among to the hypothetical invertebrate species shown in Figure 24 showed that 6 out of 10 of the zoology interviewees correctly applied their knowledge of divergent evolution to explain how homologous features such as the two-body segments, antennae and tail spine may have evolved among these invertebrate organisms. These interviewees included Z4, Z8, Z10, Z12, Z19, and Z20. These correct responses were probably the result of the instruction they had received plus the extra readings assigned during their comparative anatomy lectures. Their understanding of divergence was also evident in their selection of the most closely and most distantly related hypothetical invertebrate species.

The remaining 4 interviewees, namely, Z1, Z3, Z11, and Z19 provided incorrect phylogenograms and completely confused divergent and convergent evolutionary models. They could not differentiate the homologous and
analogous anatomical features that are products of the two processes. Some confused the above features with "derived" and "modified" features and could not make connections between the above terminologies. Interviewees' responses which deviated from this included Z1's who selected species A and C as being the most closely related, and B and D as the most distantly related. The following are two excerpts from Z1 and Z11's explanations for their choices.

Z1: "The absence or presence of the tail spine and antenna were important in my decision, because they are the most developed and probably modified features".

Z11: "In my choices I selected tail spine and eyes because they look the most recently evolved so that those organisms have more advantage over the other species. If they lived in the same environment they could out-competed the others".

The phyllograms or phylogenetic reconstruction of the 6 advanced zoology interviewees are provided in Figure 20. While the phylograms of the 4 advanced zoology students who incorrectly responses to Part 8 of the student interviews are provided in Figure 21.

The researcher, however, noted that the advanced zoology interviewees' confusion and misunderstanding of homologous and analogous features along with the evolutionary models responsible for their evolutionary development may have resulted from the overemphasis of the proximate (functional) aspects of both homologous and analogous anatomical features during instruction. She suggests that further studies should be conducted to confirm the source of this misunderstanding, and the relationship among students' understanding of homologous features, speciation, and biological classification.
Figure 20: Zoology Students' Correct Phylogenetic Reconstructions of Evolutionary Relationships among Four Hypothetical Invertebrate Species.
Figure 21: Zoology Students' Incorrect Phylogenetic Reconstructions of Evolutionary Relationships among Four Hypothetical Invertebrate Species.
Part 9: Students' Understanding of Convergent Evolutionary Model

Zoology interviewees also provided elaborate functional explanations about the analogous features of the gastrointestinal tract of the domestic vertebrate species presented in Part 9 of the student interviews. Interview questions for Part 9 are shown in Appendix E. Interviewees were presented with diagrams showing similarities and differences in morphology of the gastrointestinal tracts of five domestic species as shown.

Interviewees were asked to select the most closely related and the most distantly related on the basis of the anatomical structures of the gastrointestinal tracts of the five domestic species. Most zoology interviewees selected the pig and humans or the ruminant and rabbit as most closely related. Also most zoology interviewees selected the human and rabbit and dog and ruminant as most distantly related on the basis of the morphology of their gastrointestinal tracts. However, some students were more troubled by the similarity between the human and pig's digestive systems than between the dog and the humans. The following are students' explanations of the relationships they selected.

Z1: “For the digestive tracts, I would consider the layout of the digestive tracts first, ...(pause)... I mean the homologous structural features since they are more important in for tracing the intermediates in the organisms' evolutionary history, probably because the features are coded for by the same alleles.

Phylogenetic constructions (phylograms) showing zoology interviewees phylogenetic relationships among the five domestic vertebrate species are provided in Figure 22.
Figure 22: Zoology Students' Phylogenetic Reconstructions of Evolutionary Relationships among Five Domestic Vertebrate Species.
Part 10: Students' Scientific Reasoning and Literacy

To conclude the interviews the researcher presented every interviewee with the questions shown under Part 10 of student interview. When students were asked to describe a person they would consider to be scientifically literate, most interviewees took a while before they responded because most students rarely think about scientific literacy as the major goal of learning science. Students were asked to respond to the questions in Part 10 of the interview after the researcher reiterated the statements in test items 20, and 40 on the NOBKS questionnaire and after asking them to look at their questionnaire responses to test items 57, and 58, and 60 (see Appendix D). Most interviewees strongly agreed with test items 20, 40, and 60, and disagreed with test item 57, and 58. Below are two excerpts which represent introductory biology interviewees' explanations of scientific literacy and also two which represent advanced zoology interviewees' responses.

B1: "Scientific literacy is supposed to be important. I know Benchmarks talks about it and the Science Education Standards... (pause)... but they are very difficult to measure. How do you know who is scientifically literate and who is not?". I guess what I am trying to say is, among my kids when I will be teaching, this will be one of my least concerns".

B6: "Scientific literacy should not be an issue to about anyone who has been to college. I would assume anyone who is educated, ......(pause).... with say with a college degree is scientifically literate enough."

B121: "Science is very important for understanding the world. But science cannot give answers to all questions in this world. Things like values, and ethics. On scientific literacy, I don't think it is fair to label anyone illiterate when he believes in strong values which help him to make personal decisions about his life".
Z1: “I guess a scientifically literate person is a person who knows how science works and has the ability to use this knowledge to answer questions related to her/his everyday life”.

Z18: “My understanding of scientific literacy from my geology classes is that a person who is scientifically literate knows how science can be used to answer questions about nature. ......(pause)... which I suppose would mean that such a person should not use supernatural explanations to explain or draw conclusion about things that occur in nature”.

It is evident from interviewee B1’s responses that she had learned about scientific literacy during her courses in the College of Education. She was able to quote Benchmark for Science Literacy (AAAS, 1993) and the National Science Education Standards (NRC, 1996). However, she did not believe literacy is measurable. Following general responses from interviewees about scientific literacy, the researcher asked each interviewee to respond to questions 3 and 4 of part 10 of the student interviews. Most zoology interviewees provided responses similar to interviewees Z3’s and Z9’s responses which are provided below.

Z3: “I really don’t know much about the importance of evolution, but I guess it depends on the type of scientist you are...(pause)...if a scientist's work requires knowledge of evolution, then it is important, but if it doesn't then I don't think it is important. For example, a molecular biologist may need to know about how related a group of organisms are if he wants to compare the DNA structure of one group of organisms to another. But a plant pathologist does not need such knowledge. If I was a doctor, unless I knew I was dying....(pause)... like in the case of AIDS or something big...(pause)...like a liver transplant. Otherwise, I wouldn't accept an organ or a vaccine from any animal!. I know I would be very literate with an MD".
The above excerpts and those provided below show that when interviewees were asked about the role of science in answering value-related questions, most students who previously doubted the importance of evolution for understanding relationships among organisms continued refuting use of such a vaccine. Others who were more concerned about preserving life expressed the opinion that they would consider using such a vaccine only if their patient agreed to its use. Interviewee Z9's responses is an example of excerpts from interviewees who thought like him.

Z9: "If by that time I have already graduated from the dental school, and I am in dental practice I would have no problem accepting it for treating some of my AIDS/HIV infected patients if I know that it is safe to use it....hmm...because, if it prevents spread of the disease I would not care what type of animal cells the vaccine was developed. Be monkey cells or whatever...(pause) ....cells. However, if I would talk to my patients first..yeah...these days, you never know...(pause)...people like suing others. I wouldn't want to take the risk".

Interviewees' responses in Part 10 of the interview show that many students assume college education in a science field provides one with knowledge equivalent to scientific literacy. Zoology interviewees' responses to Part 10 of the interview show that by the time students are taking a more advanced level biology course, they have a more integrated knowledge of science and are able to use this knowledge to make decisions that affect their personal lives. However, their personal beliefs and dilemma with value-related issues seem to remain the same regardless of course level.
Summary of Qualitative Findings

Student interview results to the ten sections suggest that advanced zoology students had more knowledge and better understanding of biology that introductory biology students. Many introductory biology and a few zoology interviewees did not have adequate understanding of the scope of biological knowledge. Some interviewees expressed views suggestive of creationist and vitalistic conceptions.

Zoology students generally had a more integrated knowledge of mutation, natural selection, and the role of chance in the survival of living organisms. Their responses also showed that they had a more integrated biological knowledge than introductory biology students. In literacy assessment terms most zoology students were at least at the structural level of biological literacy while many in the introductory biology interviewees were at the nominal and function levels.

Most zoology students also correctly associated variation with genetic mutation. However, many introductory biology students had compartmentalized knowledge and did not know that the genetic make of the organism that determine which organism are selected for or against by environmental selection pressure. Some introductory biology interviewees believed that mutation only occurs in lower organisms and natural selection only occurs in higher order organisms. According to these students' explanations, natural selection is a slow gradual process, therefore, it is too slow a process to occur in organisms higher on the classification system than bacteria.
Many introductory biology interviewees did not have an integrated knowledge of the complementary nature of micro- and macroevolutionary processes as zoology interviewees did. Some of the introductory biology interviewees provided teleological explanations about the evolution of blindness in the cave salamanders. To them, blindness seemed to be a "perfect irreversible state". Some interviewees used Lamarckian explanations explaining that evolution of blindness was based on the "need" of the cave salamanders.

Generally students who had spent over two years in college and had completed at least three biology courses, particularly, from the zoology class provided more elaborate and scientifically correct explanations related to indeterminable outcomes of natural selection. They predicted that the blind salamanders may or may not be able to evolve sight in the presence of light depending on genetic mutations and the selection pressure placed on them for development of sight.

Most zoology students understood divergent and convergent evolutionary models. Many also related these models to understanding speciation and classification. Many interviewees did not understand scientific literacy even though they had responded correctly to test items 20, 40, and 60 in the NOBKS questionnaire. Personal beliefs and value-related issues were predicaments for many interviewees. Most introductory biology interviewees explained that evolution is not important for understanding the nature of biological knowledge. In fact, 8 out of 10 introductory biology students
explained that they see no "relevance" in including the theory of evolution by natural selection in the high school and college biology curricula. The two interviewees who saw "relevance" in learning the theory of evolution with respect to comparative biological studies included interviewees B55 and B75. Both of these interviewees had taken more than four biology course including those they completed in high school. Both were also microbiology majors, with B55 coming from the College of Basic Sciences and B75 from the School of Veterinary Medicine.

Among the advanced zoology interviewees, most agreed that learning evolution has "relevance" for understanding biological classification, observed similarities and differences among living organisms. However, none of the advanced zoology interviewees knew that evolution is the unifying principle of biological knowledge. Qualitative findings of these study suggest that instructional methods currently used in college biology classroom do not present biological concepts to students in terms of unifying principles. Secondly, most students who participated in this study din not know or recognize the theory of evolution as the unifying principle for biological knowledge. Thirdly, many interviewees did not related scientific and biological literacy to their ability to utilize scientific and biological knowledge to make personal and public decisions.
CHAPTER 5: SUMMARY AND CONCLUSION

Summary of Study and Research Findings

This study examined students' understanding of the nature of biological knowledge among 121 college students registered in an introductory biology and a zoology (comparative anatomy) course at Louisiana State University, Baton Rouge Campus. Adequate understanding of the nature of science has been emphasized in various science education reform documents as a major goal of science education (AAAS, 1993; BSCS, 1996; NRC, 1996; Rutherford & Ahlgren, 1990). It is well-known fact that biological knowledge is a multilayered type of scientific knowledge which requires an integration of knowledge from within the discipline and those from the physical sciences.

The National Academy of Sciences (NAS, 1998) emphasizes that the evolutionary nature of biological knowledge should be taught to all students in order to promote students' understanding of the nature of science and to reinforce the learning of science as a way of knowing. The above recommendations and findings from previous science education studies (Barnett et al., 1983; Demastes, 1994; Demastes et al., 1996a; Demastes et al., 1996b; Good et al., 1992; Nelson, 1986; Rudolf & Stewart, 1998; Scharmann & Harris, 1992) provided the impetus for the present study. The above studies suggest that adequate students' understanding the theory of evolution by natural selection promotes students' understanding of the nature of science and the nature of biological knowledge. The present study was guided by Ausubel's cognitive theory, Ausubel-Novak-Gowin's theory of meaningful
learning also called Ausubel-Novak-Gowin's assimilation theory, and Posner et al.'s conceptual change theory. Using these theories of learning, conceptual change among students was assumed to be a rational activity. Learning was assumed to be a result of students using their metacognitive skills to allow them to see deficiencies in their own knowledge.

Learning was also assumed to be a result of students' seeking scientifically-acceptable explanations when students are dissatisfied with their own intuitive reasons about natural and biological phenomena (Posner et al., 1982). This rational mode of learning, particularly in biology classrooms where students are confronted with concepts such as evolution allows students to develop conceptual change. Conceptual change is a result of better understanding and acceptance to use scientific concepts in explanation of natural phenomena. Toulman (1972) has referred to this as increase in students' conceptual ecology.

With the above theoretical framework to guide the study, the researcher and her major professor as principal investigators obtained permission to conduct research with human subjects from the Office of the Dean of the College of Education. A copy of the IRB is shown in Appendix A. All students who agreed to participate were asked to sign the student release form shown in Appendix B. A pilot study and observations of research settings was conducted in the fall semester of 1997 to develop the 60-item Likert-scale NOBKS questionnaire shown in Appendix D from a preliminary instrument shown in Appendix C. It also allowed the researcher to develop standardized interview
questions shown in Appendix E. These research instruments allow the researcher to examine students' conceptions related to the nature of biological knowledge using quantitative and qualitative methods. The final study was conducted and completed at the end of the spring semester of 1998.

Analysis of Part A of the NOBKS questionnaire and complementary student interviews allowed the researcher to answer primary research question 1: "What conceptions related to the general nature of biological knowledge do college introductory biology and advanced zoology students hold?". The study showed that at least 80% of the college biology students have adequate knowledge of the scientific methods used to derive scientific and biological knowledge. The study also showed that college students have numerous prescientific conceptions about living organisms and biological phenomena. Prescientific conceptions identified to be related to students' conceptions of the nature of biological knowledge included creationist, vitalist, teleological, nonreductionist and nonemergentist conceptions.

Analysis results for Part A of the NOBKS questionnaire also show that few (<59%) of college students have scientifically-correct understanding of the scope and limits of biological knowledge. About half (51%) of the students in this study knew that biological knowledge provides answers to most questions about living organisms. About 36% of the students responded correctly that biology cannot answer questions about the meaning of life. However, only about 17% of the students responded that biology cannot answer questions about human values. These students did not know that value-rated issues are
often difficult to find empirical evidence for. These students did not know that value-laden issues are usually outside the realms of nature hence outside the realms of science. Students' interview responses to questions in Parts 2 and 3 of the interview complemented the about results.

Analysis of students' responses to Part B of the NOBKS questionnaire provided answers to primary research question 2: "What conceptions related to knowledge of evolutionary biology do college biology and zoology hold?" Descriptive results showed that at least 59% of the students who participated in this study did not understand the importance and consequences of evolution (factor B1). However, the study also showed that most (80-100%) of the students in this study had encountered the theory of evolution by natural selection and related evolutionary concepts (factor B2) in their biology courses. Students' responses to questions in Parts 4, 5, and 6 of the interviews complemented the above findings.

Analysis of students' responses to Part C of the NOBKS questionnaire provided answers to primary research question 3: "What conceptions related to knowledge of homologous and analogous features and evolutionary models do college biology and advanced zoology hold?" Descriptive showed that at least 60-80% of the introductory biology and 80-100% of the advanced zoology students who participated in this study understood biological classification as based on understanding evolutionary similarities and differences among organisms. However, more advanced zoology students understood the usefulness of divergent and convergent evolutionary models for studying and
making inferences about the structural similarities and differences observed among living organisms. Advanced zoology students also used knowledge of evolution to explain the process of speciation among living organisms during student interviews. Part 7, 8 and 9 of the qualitative results show students responses that complemented the above quantitative results.

For secondary research question 1: “How do students’ conceptions related to the general nature of biological knowledge relate to their knowledge of evolutionary biology, and knowledge of homologous, and analogous anatomical features?”. Pearson’s correlation analysis was conducted on the factors extracted by means of factor analysis in order to answer this research question. Pearson’s correlation results showed that students who do not understand the importance of the theory of evolution by natural selection (factor B1) hold prescientific conceptions about the origin and nature of change in living organism (factor A2). Prescientific conceptions identified included creationism, vitalism, nonreductionism and nonemergentism. Similarly, students who hold prescientific beliefs or conceptions (factor A2) did not understand the importance of evolutionary models (factor C2) in understanding similarities (such as homologous features) and differences (such as analogous features) that are observed among living organisms.

Secondary Research Question 2 is: “Do course, students' age, gender, major or years in college influence students' conceptions related to the nature of biological knowledge?” was answered by means of MANOVA. MANOVA results showed the course students were registered in had a statistically
significant influence on students' responses about the nature of biological knowledge. Conceptions that were influenced most by course included students' conceptions related to scientific methods (factor A1), understanding of the scope and limits of biological knowledge (factor A3), understanding of the importance and consequences of evolution (factor B1), and students' understanding of divergent and convergent models for studying homologous anatomical features (similarities) and analogous anatomical features (differences) among living organisms. The remaining students' characteristics, namely, gender, major, years in college, and age had no influence on the above factors and all the other factors identified in this study.

Lastly but not least, findings of this study suggest even though the evolutionary nature of biological knowledge is emphasized in all major science education reform documents (AAAS, 1990; AAAS, 1993; BSCS, 1993; NRC, 1996; NAS, 1998), the instructional methods currently used in college biology classroom do not seem to present students with this view of the nature of biological knowledge. These findings also suggest that presentation of biological concepts to students are made in a fragmentary manner rather than using the unifying biological principles. Therefore, most college biology students who participated in this study did not recognize the theory of evolution as the unifying principle for biological knowledge and many did not relate scientific and biological literacy to their ability to utilize scientific and biological knowledge to make personal and public decisions.
Significance and Implications of Findings

This study examined students' understanding of the nature of biological knowledge. It also indirectly assessed conceptual change among students at an introductory biology level and an advanced biology (zoology) course level. Gunstone and White (1992) describes conceptual change studies which examine student's understanding as studies which "probe understanding as a means to improve classroom teaching". The implications of this study in terms of instruction are twofold.

In spite of the fact that instructional attributes were not the focus of this study, the researcher's observations and findings of this study suggest that instructional methods that integrate philosophy of biology with content-specific biological knowledge promote students' understanding of the nature of biological knowledge. Secondly, this study has provided insight into areas that need to be addressed through design of biology curricula that meet students' learning needs, and teaching methods that promote conceptual change among students. Conceptual change instructional methods have been proven to be effective means of helping students to see deficiencies in their own way of thinking (Smith et al., 1993). Findings of this study suggest that such methods may be necessary to address and counteract deeply-rooted students' prescientific conceptions identified among the students in this study.

In terms of students' learning, the study has several implications. Firstly, the study suggests that students' understanding of the scientific methods (factor A1) are not related to their understanding of any other biological concepts.
except their understanding of models such as divergent evolutionary models. This finding stands out distinctly, particularly, among students' incorrect responses which show that students do not understand the importance of evolution in biology. This finding suggests that models are good means of improving students' understanding of complex and abstract biology concepts.

Secondly, the study provided insight into relationships among students' prescientific viewpoints about evolution and its consequences, conceptions about natural selection, and students' belief systems. The study showed that students who do not understand the importance of the theory of evolution by natural selection (factor B1) hold prescientific conceptions (factor A2) about the origin (creationism) and about the nature of change in living organisms (vitalism, nonreductionism and nonemergentism). Similarly, the study showed that students who hold prescientific beliefs or conceptions (factor A2) do not understand the importance of evolutionary models (factor C2) in understanding similarities (such as homologous features) and differences (such as analogous features).

Thirdly, quantitative and qualitative findings of this study showed that many college students are not able to distinguish between genetic processes and evolutionary processes, or proximate and ultimate processes because they do not understand the various levels of organization at which biological processes occur. Instruction which emphasized and reminded students of these levels of organization would improve students' understanding of biological processes at micro- and macroevolutionary levels. Lastly but not least,
quantitative findings and students' interview findings show that the existence of prescientific conceptions in students' conceptual frameworks directly and indirectly influence their explanations. This in turn, influences their conceptual ecology and the level of scientific and biological literacy they are able to attain.

**Limitations of Study**

The goal of this study was to investigate students' general conceptions related to the nature of biological knowledge. However, the choice of the research subjects and the courses used in study limited the generalizability of the findings of the study. Firstly, it is obvious that a major limitation of the study is the zoological bias apparent in the assessment of students' conceptions of the nature of biological knowledge. Students' conceptions related to the nature of biological knowledge were assessed using biological concepts that are more applicable to zoological disciplines than to botanical disciplines. Students' understanding and viewpoints related to the origin of life, evolutionary processes, homologous, and analogous anatomical features as evidence and products of evolutionary processes were used as probes to assess students' understanding. The researcher's educational background partly accounted for this bias.

Secondly, the choice to use students registered in an introductory biology course for science majors and a zoology (comparative anatomy) course for biology majors further increased the zoological bias of the study. This biased research approach allowed for an assessment of students' understanding and conceptions related to the nature of biological knowledge from...
microevolutionary and macroevolutionary perspectives. The third limitation of the study stems from the use of the researcher-designed NOBKS questionnaire as a research instrument. The following suggestions should, therefore be considered during future studies.

**Suggestions for Future Research**

Considering the steps taken during the development and reliability testing of the NOBKS questionnaire during a pilot study (Beech & Harding, 1990; Berdie et al., 1986; Hord, 1987; Koballa, 1984; Koulaidis & Keratsinou, 1988; and Likert, 1973) plus the reliability testing of the questionnaire with the actual research subjects at the beginning of the spring semester of 1998, the NOBKS questionnaire can be considered a reliable instrument for assessing college students' understanding of the nature of biological knowledge (Hatcher, 1994).

However, findings of this study need to be confirmed with a much larger group of college students at more than two college level biology courses used in this study. This would not only test the construct validity of the NOBKS questionnaire test items, it would also identify concepts that need to be modified to improve the usefulness of the questionnaire. The modification of the NOBKS questionnaire would also extend the usefulness of the questionnaire for studies with biology students outside zoology-related biology courses. This would allow for a broader identification of biology students' prescientific conceptions.

Secondly, the consistency among the various quantitative results obtained in this study, along with those from the qualitative research findings
suggest that students' prescientific conceptions may have logical relationships. It is, therefore, suggested that similar studies conducted using the NOBKS questionnaire developed in this study with a larger sample of students be used to explore further the nature of such relationships. Such studies would allow for development of remedial teaching strategies that can be used to address prescientific conceptions that are related.

Thirdly, results of this study showed that course had a statistically significant influence on students' responses to the NOBKS questionnaire. It is suggested that future research be conducted to investigate teaching strategies used by an instructor teaching both a lower and an upper level college biology course to examine the influence of his/her teaching methods and course content on students' conceptions.

Linn, Pulos and Gans (1981) found that such studies can be used to identify instructional methods and techniques which facilitate student learning. Incorporating teaching methods that address philosophical ideals and subject-specific views related to what counts as a scientific or biological explanation would facilitate students' understanding of the nature of science as well as the nature of biological knowledge.

Lastly but not least, since only a few previous studies are available on students' conceptions related to the homologous and analogous anatomical features that living organisms of the animal kingdom share, it is suggested that more studies be conducted in this area to provide more insight about the influence of students' understanding of homologous and analogous anatomical...
features as products of evolutionary processes. It is also suggested that to a
similar study be conducted from a botanical perspective to assess students'
"grand conceptual schema" and understanding of the evolutionary nature of
biological knowledge.
REFERENCES


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APPENDIX A: IRB FOR CONDUCTING RESEARCH WITH HUMAN SUBJECTS

Title: Undergraduate students's understanding of the nature of biological science, evolution by natural selection, homologous and analogous features: implications for conceptual change.

Investigators: Gloria M. Ameny - Doctoral student
Curriculum & Instruction.

Dr. Ron Good - Professor of Science Education
Principal Investigator and Major Professor

Principal Investigator Statement:
I have read and agree to abide by the Louisiana State University policy on the use of human subjects. This project will be conducted in accordance with federal guidelines for Human Protection. I will advise the Office of the Dean and the University’s Human Subject Committee in writing of any significant changes in the procedures detailed above.

Signature: [Signature]
Date: 9/2/97

Faculty Supervisor Statement (for student research projects):
I have read and agree to abide by the Louisiana State University policy on the use of human subjects. I will supervise the conduct of the proposed project in accordance with federal guidelines for Human Protection. I will advise the Office of the Dean and the University’s Human Subject Committee in writing of any significant changes in the procedures detailed above.

Signature: [Signature]
Date: 9/3/97

Reviewer recommendation:

☑ exemption from IRB oversight. (File this signed application in the Dean’s Office.)

☑ expedited review. (Follow IRB regulations and submit 2 copies to the Dean’s Office.)

☑ full review. (Follow IRB regulations and submit 12 copies to the Dean’s Office.)

Barbara S. Fuhrmann
Name of Authorized Reviewer (Print)

Signature / Date

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APPENDIX B: SAMPLE OF STUDENT RELEASE FORMS

Research Participant's Code: ___________________

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

I, ____________________________, contact telephone ___________________ do hereby give Gloria Ameny permission to use my responses to the questionnaires and interviews she will administer as part of a research project, designed for use in preparation and completion of her dissertation. I understand that my participation in her research will in no way affect my grades for the BIOL 1201 or ZOOL 3152 course.

By signing this document I release the said information for her to use with the understanding that it will be kept confidential and at no time will my name be used or connected with the information. Also by signing this document, I do agree to participate from the beginning up to the end of the study by completing all the questionnaires, test items and interviews as required.

Demographic and biological knowledge background:

Biology courses completed in high school ________________________________
College undergraduate level Biology courses completed _____________________

Year of birth ___________________ Gender _________________________________

Years in college _______________ Major (&College) ________________________

Signature of participant ______________ Date ______________

Signature of investigator (s) ______________ Date ______________

If you have any questions please feel free to contact me at any time.

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Thank you for your participation
APPENDIX C: PILOT STUDY PRELIMINARY RESEARCH INSTRUMENT

For each of the following statements, use the letter A if you “Disagree” with the statement, B if you “don’t know”, and C if you “Agree” with the statement. Explain of a separate sheet of paper why you made that choice and why you believe that your position is correct.

1. Biological sciences are not grounded in the natural world.

2. Biological sciences can provides answers to all questions about the living world.

3. Biological sciences cannot answer supernatural questions.

4. Biological knowledge has a dual nature, one that is a process, and another that is the product of that knowledge.

5. Biological sciences are a stable body of knowledge, but the postulates of its theories constantly being modified through research.

6. Careful observations, hypotheses testing, and making conjectures are important steps in the establishment of biological knowledge.

7. Chance plays no role in the changes observed in living organisms.

8. All living organisms were “created” as they appear today by “special creation”.

9. Evolution is always directed towards perfection of organisms by an inherent force in the organisms.

10. Living and nonliving things are not composed of similar materials.

11. Living and nonliving things are not subject to the same physical laws.


13. The whole organism is no greater than the sum of its parts?

14. A theory to biology is what a law is to physics.

15. A complete biological explanation is one that incorporates both proximate (functional) as well as ultimate (evolutionary) causation.
16. Biological sciences can answer "what" and "how" and sometimes "why" questions about living organisms.

17. Classification and systematics are best understood with similarities and differences brought about by evolutionary change are understood.

18. Logical thinking, careful observations, models and predictive statements (hypotheses) play a big role in understanding events occurring in living organisms.

19. A good biological scientist is always willing to change his/her mind when presented with evidence.

20. Biological knowledge is a universal type of knowledge, with many scientists acting as "players" in the generation of this knowledge.

21. Biological literacy is measured by the ability of a person is to make connections between biology and the physical sciences.

22. A biologically literate individual is one who uses biological knowledge to make personal and public decisions about events affecting her life.

23. The theory of evolution is the unifying theory of biology.

24. Natural selection is the differential survival and reproduction of individuals in a populations.

24. Natural selection acts on phenotypes rather than genotypes of organisms in a population, leading to changes in the populations.


27. Changes in allele frequencies are the result of natural selection, migration, genetic drift, or mutation.

28. Natural selection is a random process with beneficial, detrimental or neutral effects to the species involved.
29. Variation among individuals in a populations is important for the survival of the species in that population.

30. In the absence of variations, individuals in a population will become extinct when vast changes occur in the environment.

31. Knowledge of evolution is one that transcends disciplinary boundaries in the natural sciences.

32. Understanding biological evolution allows for the understanding the history of life on earth, and the dependence of life on the physical environment.

33. The term adaptation refers to change in behavior or structural features of an individual within a specific environment.

34. Fossils provide evidence of similarities and differences in characteristics between extinct and contemporary living organisms.

35. The theory of evolution is supported by the fact that there is less chance of finding complex contemporary species of living organisms in older sedimentary rock strata.

36. The theory of evolution is supported by the fact that fossils of only the simplest organisms have been found in the oldest fossiliferous strata.

37. The theory of evolution by natural selection provides a logical and intellectually plausible explanation of the similarities and differences observed among living organisms.

38. Do you agree with the statement that: "nothing in biology makes sense except in the light of evolution?"

39. Biological evolution provides the unifying theory for understanding all content areas of biology including comparative anatomy.

40. The relationships among organisms through evolutionary descent explains the adaptive mechanisms and differing survival rates of organisms in various environments.
41. The theory of evolution by natural selection provides a model which supports the occurrence of teleological changes in living organisms.

42. Understanding the history of evolutionary biology and its relationships with comparative anatomy us to experience biological science as a process and as a way of knowing.

43. Similarities and differences in features among vertebrates are best explained by means of typological explanations.

44. Species with a common ancestry continue to be similar and show homology in anatomical features and body design because natural selection preserves heritable characteristics.

45. Both evolutionary biology and comparative anatomy demand use of evidence in understanding the characteristics of living organisms.

46. Homologous and analogous features are products of divergent and convergent or parallel evolutionary processes.

47. Homologous features are structural features found in two or more taxa, in which they have same embryonic precursors, similar relationships to surrounding organs systems, and are traceable to a common ancestral species.

48. Homologous features can be linked by intermediate structural features in extinct relatives in their evolutionary history.

49. Analogous features are structural features in two or more taxa, which perform similar functions but are not traceable to a common or intermediate ancestry.

50. The understanding comparative anatomy and its relationship to biological evolution provides an avenue for biological literacy, and for scientific literacy.

51. An adequate understanding of biological concepts and how biological knowledge is derived is very important.

52."The probability that natural selection could build an anatomical feature as complex as an eye is equal to the probability that a hurricane could pass through a junkyard and build a 747".

53. Scientific knowledge rarely troubles us if we discover that our natural world is not as we perceive it to be.
54. Scientific knowledge usually surprises us if we discover that our world is not as we perceive it to be.

55. Scientific knowledge sometimes forces us to discard beliefs we have long held about the grand scheme of nature.

From question 56-64, select the best answer for the multiple choice question provided and provide a reason for your choice in the space provided.

56. A related set of hypotheses that collectively explain some aspect of the natural world is a scientific _____________.
A. Prediction  B. Test  C. Theory  
D. Authority  E. Observation.
Reason for your answer?

57. A scientific approach to explaining various aspects of the natural world include all of the following except _____________.
A. Hypothesis  B. Testing  
C. Systematic observations.  D. Faith and simple conscience
Reason for your answer?

58. The earth is approximately how many years old?
A. 4.5 billion years.  
B. 2,000 years.  
C. 3.5 billion years.  
D. 10,000 years.  
Reason (s) for your choice?

59. Through radiometric dating of fossils, the first living organisms on earth were found to have existed approximately how many years ago?
A. 65 million years  B. 3.5 billion years  
C. 10,000 years  D. 2,000 years  
Reason for your choice:

60. The fossil record of evolution correlates with evidence from _____________.
A. Geologic time  B. Radiometric dating  
C. Comparative morphology.  D. All of the above
Reason(s) for your choice?
61. Through the study of geologic record we know that evolution of life is linked to ________________.
A. Tectonic movements of the earth's crust.
B. Bombardment of the earth by terrestrial objects.
C. Profound shifts in land masses, shorelines, and oceans.
D. Physical and chemical evolution of the earth.
E. All of the above.
Reason(s) for your choice?

62. The observable traits of an organism are collectively called its ________________.
A. Phenotype
B. Genotype
C. Pedigree
D. Sociobiology
Explain your answer?

63. Natural selection acts on ________________ in the presence of variation.
A. Genotypes
B. Phenotypes
C. Pedigree
D. Sociobiology
Reason for your choice?

64. Variation in the traits of offspring is increased by the mix of ______ allele combinations of two __________ gametes at fertilization.
A. Similar; similar
B. Different; similar
C. Different, different
D. Similar; similar
Reason for your choice?

65. Match the following individuals with the conceptions they proposed.
A. Cuvier
B. Lamarck
C. Malthus
D. Lyell
E. Darwin and Wallace
I. Populations outgrow resources ______.
II. Theory of natural selection ________.
III. Inheritance of traits acquired through environmental pressures and internal desires for change__________.
IV. Catastrophism ____________.
V. Geologic evidence that the earth is extremely ancient ________

66. The two major sources of variation among individuals in a population are ________________
A. Genetic and environmental factors.
B. Disease epidemics and mutations.
C. Only A is correct.
D. Both A and B are correct.
E. None of the above
Reason(s) for your answer?
67. Which of the following statements about mutation is not true?  
A. Mutations arise randomly.  
B. Most mutations have harmful effects on organisms involved.  
C. Most mutations are beneficial to the organisms.  
D. Mutation is sometimes necessary for natural selection.  
Reason for your answer?

68. Which of the following statements about natural selection is not true?  
A. Natural selection occurs randomly.  
B. Natural selection does not occur randomly.  
C. Natural selection is always beneficial to organisms.  
D. Natural selection may be detrimental to organisms.  
E. Natural selection occurs all the time in any population of living organisms.  
Reason(s) for your answer?

69. Natural selection and mutation are processes associated with changes in the _________ and _________, respectively, of variants of organisms in a population.  
A. Genotype; phenotype  
B. Phenotype; genotype  
C. Gene flow; genetic drift  
D. Genetic drift; gene flow  
Reason for your answer?

Use the following information about a population of lions to answer questions 70-73. There are only four mature males in the population of lions, namely; Ben, George, Sporty and Sandy. Ben has the greatest number of females in his den. George is a very large, healthy and strong lion. Sporty is very agile - when the area in which he lived was destroyed by fire Sporty quickly moved his pride to a new area and change his feeding habits. Sandy was killed by an infection resulting from a cut in his foot. Additional characteristics are provided in the table (same as Table 20 in Appendix E)

70. Which of the four male lions is most "fit" or successful in this generation of lions?  
A. Ben  
B. George  
C. Sporty  
D. Sandy  
Reason(s) for your answer?

71. Which of the four male lions is least "fit" or successful in this generation of lions?  
A. Ben  
B. George  
C. Sporty  
D. Sandy  
Reason(s) for your answer?
72. Using your knowledge of the mechanism of natural selection, which of the following do you think would happen to Sandy's offspring?

A. They will all die during childhood.  B. They will all die early like Sandy
C. They will live successfully to old age.  D. All of the above.
E. None of the above.

Reason(s) for your answer:

73. The best way of measuring Darwinian "fitness" in the above population of lions is:

A. The size of the offspring a lion produces during its lifetime.
B. The number of females it associates with during its lifetime.
C. Number of offspring it produces that survive to breed.
D. It's ability to survive harsh environmental conditions.
Reason(s) for your answer:

74. You are a biologist studying a population of Drosophila Species, or fruit flies in the Hawaiian archipelago. You find that most of the 700 species of fruit flies in the archipelago are restricted to a single island. One hypothesis to explain this pattern is that each species diverged after a small number of flies had colonized a new island, in a mechanism called:

A. Sexual reproduction  B. Genetic equilibrium
C. Disruptive selection  D. The founder effect
E. Assortative mating

Reason for your answer.

75. You are a biologist studying the influence of seasons on leaf sizes in a natural population of plants. The second season was particularly drier than the first season. In the following year you find that the average leaf size in this plant population is smaller than the year before, but the overall variation and the population has not changed. Your experiment confirms that the smaller leaves are better adapted to dry conditions. Which of the following would you predict has occurred?

A. Genetic drift  B. Directional selection
C. Stabilizing selection  D. Disruptive selection
E. The founder effect

Reason for your answer?
Using the multiple-choice responses A-D, answer questions 76 through 80 and in the space provided, and explain why you made that choice.

A. Analogous  B. Homologous  C. Primitive  D. Derived

76. An operational definition of _______ structures are features in the body in two or more species or taxa with similar locations and relationships to surrounding tissues.
Provide an example ________________.
Explain why you made this choice?

77. Two or more non-homologous features that have the same function are described as ______________ features.
Provide an example________
Reason for your choice?

78. A feature that has evolved earlier than another one in the course of phylogeny is called a __________ feature.
Provide an example___________
Reason for your choice?

79. Due to mosaic evolution, an organism cannot be described as ____ or ____.
Reason(s) for your choices?

80. The wings of a hummingbird and a bat are ____________. Explain why?

81. A descriptive Latin name may be given to all _______ features in different organisms even if they function or appear differently in shape or size e.g. the muscle M. piriformis in humans and in the cat. Explain why?

For each of the following questions 82 through 85, select the letter that gives the best description of the feature in question, and provide an explanation for your choice.

82. ______ features are features in two or more species that have evolved independently.
A. Convergent  B. Divergent  C. Reduced  D. Derived  
Your explanation?

83. A _______ is a monophyletic group of organisms which has evolved from a common ancestor.
A. Taxon  B. Category  C. Class  D. Family  
Explain you choice?
84. Check as many as apply and provide an explanation for each. A reduced feature can be ________.
   A. Primitive       B. Derived       C. Special       D. Generalized
   Your explanations?

85. The evolutionary history of the human hand is best described as ________.
   A. Primitive (plesiomorph) and generalized
   B. Derived (apomorph) and generalized
   C. Primitive (plesiomorph) and specialized
   D. Derived (apomorph) and specialized
   Explain your choices?

In the following section, use the multiple-choices A - E to answer questions 86 and 87.

A. Homologous       B. Analogous       C. Convergent       D. Primitive       E. modified

86. The salt glands of the sea gull and the human kidneys are ________, but the former is better adapted than the latter in its efficiency to eliminate NaCl from the body. Explain why?

87. The muscles in the trunk of the South American electric eel (Electrophorus) and of the electric ray Torpedo are____ features which generate, store and discharge electric currents to protect these organisms from predators. Explain how this electric current is generated?

88. Are the ribs in reptiles homologous to the ribs of mammals? Explain?

89. What is meant by a scientific theory. Provide an example of a biological theory?

90. The embryos and often adults of all ___ have a notochord, a tubular dorsal nerve cord, a pharynx with gill slits in the wall, and a distinct tail extending past the anus.
   A. Echinoderms       B. Tunicates and lampreys
   C. Vertebrates       D. Both B and C
   Reason for your choice?

91. The ____________ were the earliest jawed fishes that lived as bottom-dwelling scavengers.
   A. Placoderms       B. Ostracoderms
   C. Cephalosponds    D. Cyclostomes
   Reason for your choice?
92. Gill slits in jawed fishes are used for ________________.
A. Respiration   B. Circulation   C. Food trapping
D. Water regulation   E. Both A and C
Reason for your choice?

93. Existing aquatic vertebrates include ________________.
A. Jawed, armored fishes   B. Jawless fishes
C. Bony fishes   D. Both B and C
Reason for your choice?

94. The first vertebrates to appear were the __ during the Cambrian. They were jawless fishes, and their only living descendants are the lampreys and hagfishes.
A. Lancelets   B. Placoderms
C. Ostracoderms   D. All of the above
Reason for your answer?

95. A shift from reliance of on _____ and ______ was pivotal in the evolution of all vertebrates.
A. The notochord; a backbone   B. Gills; lungs
C. Filter feeding; jaws   D. all the above.
Reason for your answer?

96. The bony fishes include ________________.
A. Ray-finned fishes   B. Lungfishes
C. Lobe-finned Fishes   D. All of the above
Reason for your answer?

97. Adaptations that have permitted reptiles to escape dependency on aquatic habitats were ________________.
A. Tough skin   B. Internal fertilization   B. Amniotic eggs
D. Efficient kidneys   E. Both B and D   F. All the above
Reason for your answer?

98. The only amphibians to entirely escape dependency on aquatic habitats are the ________________.
A. Salamanders   B. Caecilians
C. Desert frogs   D. None of the above
Reason for your answer?

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99. The characteristic features of ostracoderms were ________________.
   A. Fusiform body       B. Hypocercal tail
   C. Terminal mouth      D. Flexible body scales
   E. All of the above    F. None of the above
   Reason for your answer?

100. Using the given letters, match the organisms with the appropriate features.

   _____ Jawless fishes  A. Complex brain.
   _____ Cartilaginous fishes  B. Respiration through skin and lungs.
   _____ Reptiles          C. Include hagfishes.
   _____ Mammals           D. Include sharks and rays.
   _____ Birds             E. Complex social behavior
                           G. First with amniote eggs

   For the following structured questions 101 - onwards, write your answers on
   the separate sheets provided.

101. In biology, living organisms are studied and classified using universally
   accepted procedures called taxonomy and systematics. Explain how biologists
   use these procedures to classify living organisms.

102. You have studied several evolutionary concepts in this biology course
   including natural selection. Could you explain how natural selection occurs in a
   population of organisms?

103. Explain the mechanism of natural selection. How is natural selection
   different from mutation? Using the table provided, indicate the level of
   organization at which each of the two biological processes occur (see Table 19
   in Appendix E)

104. What role do you think variation plays in the survival of individuals in a
   populations of organisms.

105. What is the importance of having a high reproductive capacity during an
   organism's lifetime?

106. What is meant by the term adaptation?

107. Do you agree or disagree with the statement: "Nothing in biology makes
   sense except in the light of evolution". Explain why?

108. What is your personal position on the teaching of evolution as the unifying
   principle for organizing the biological concepts?
109. What is your personal opinion on the teaching of evolution as the central theme for guiding biology instruction?

110. Why do you think biologists study the similarities and differences in the structural features and physical characteristics of living organisms?

111. Has your knowledge of comparative vertebrate anatomy been enhanced, inhibited or remained the same as a result of better understanding of the evolutionary basis and history of biology?

112. What is meant by a species of living organisms?

113. Do you think understanding of evolution is important for understanding speciation?

114. A species of cave salamanders are blind because their eyes are nonfunctional. However, analysis by biologists has revealed that they still possess genetic and anatomical features suggestive of having had sighted ancestors. How do you explain the evolution of blind eyes from their sighted ancestors?

115. If these present blind salamanders are removed from dark caves and reared in a well-lit laboratory environment, do you think they will evolve sight and begin to see like their ancestors did? What factors do you consider in your prediction about the evolution of sight in these salamanders?

116. Systematists use similarity in genetic and morphological features to classify species of living organisms. Comparative anatomists consider both anatomical similarities and differences to reconstruct the phylogenetic history of living organisms. Use the information provided on the following four hypothetical invertebrate organisms to complete the phylogenetic tree (phylogram) below (see Figure 24 in Appendix E)

a) Which of the two taxa above are most closely related?

b) Which of the two taxa above are most distantly related?

117. Suppose you were able to dissect five vertebrate species including a human cadaver to expose and identify the segments present in their gastrointestinal tracts. The figure provided shows what the gastrointestinal tracts would look like (see Figure 25 in Appendix E)

a) Using the information on the figure above, construct a phylogenetic tree (phylogram) to show the evolutionary relationships among the five vertebrate species.
b) Which of the vertebrate species would you consider most closely related and which ones are most distantly related?

118. In both the hypothetical invertebrate taxa and the vertebrate species represented by their gastrointestinal tracts above;

(a) How did your knowledge of homologous or analogous features influence your decision about the relationship among those organisms?

(b) Was knowledge of evolutionary relationships among these organisms of help in your decisions?

119. Suppose you were a medical practitioner at the time that an experimental HIV/AIDS vaccine had been developed and approved by the U.S Department of Food and Drug Administration (FDA) and the Center for Disease Control in Atlanta, Georgia for experimental use in AIDS/HIV infected human patients. You have also learned that the vaccine was developed in a highly reputable research laboratory using attenuated viral DNA that had been cultivated on rhesus monkey cell lines infected with the AIDS/HIV virus. Comprehensive testing of the vaccine (including safety tests) have revealed that the vaccine is effective in preventing new cases and the spread of the AIDS/HIV virus among human patients already infected with the virus.

(a) Would you consider using this vaccine in your medical practice?

(b) Why? (Provide all the medical, ethical, or value-related reasons for your choice).

120. As you read newspapers and scientific articles, listen to daily news, and watch scientific programs on television, do you think your knowledge of evolutionary biology has enhanced your ability to understand the characteristics of living organisms including ourselves?
APPENDIX D: FINAL NOBKS QUESTIONNAIRE

For each of the following questionnaire test items, circle the number that best represents your opinion, belief or knowledge about the given statement, where, 1 = Strongly disagree, 2 = Disagree, 3 = Agree, and 4 = Strongly agree.

Part A: Concepts related to the Nature of Biological Knowledge

1. Biological sciences are not grounded in the natural world....1 2 3 4

2. Biological knowledge provide answers to most questions about the living world.................................1 2 3 4

3. Biological sciences cannot answer questions about the meaning of life.............................................1 2 3 4

4. Biological sciences cannot answer questions about human values..................................................1 2 3 4

5. Biology is a derivative of knowledge from various life science disciples..............................................1 2 3 4

6. Biological knowledge is grounded in theories supported by scientific research...............................1 2 3 4

7. Careful observations, hypotheses testing, and conjectures are important steps in the establishment of biological knowledge .........................1 2 3 4

8. A complete biological explanation incorporates evolutionary and functional attributes of a biologic phenomenon........................................1 2 3 4

9. Biological sciences answer "what" questions about living organisms....................................................1 2 3 4

10. Biological sciences answer "how" questions about living organisms......................................................1 2 3 4

11. Biological sciences can answer "why" questions about living organisms..............................................1 2 3 4

12. All living organisms were created as they appear today by special creation......................................1 2 3 4

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13. Evolution is directed towards perfection of organisms by an inherent force in living things.

14. Living and nonliving things are not composed of similar atoms and molecules.

15. Living and nonliving things are not subject to the same natural or physical laws.

16. A mystic, non-measurable motive force exists in living things.

17. The whole organism is no greater than the sum of its parts.

18. Chance plays little role in the changes observed in living organisms.

19. A theory to biology is what a law is to physics.

20. A scientifically literate individual uses biological and other scientific knowledge to make personal and public decisions.

Part B: Concepts Related to Evolutionary Biology

21. Knowledge of evolution is not important for understanding biological concepts and processes.

22. Knowledge of organic evolution does not add meaning to the concept of change as discussed in biology.

23. The theory of evolution is not the unifying theory of biology.

24. Knowledge of evolution does not enhance one's understanding of the history of life on earth, or the dependence of life on the physical environment.

25. Knowledge of evolution does not transcend disciplinary boundaries in the natural sciences.

26. Natural selection is the primary mechanism responsible for biological evolution.

27. Natural selection is the differential survival and reproduction of individual organisms in a population.
29. Natural selection is always beneficial to the organisms involved.
30. Natural selection may be detrimental to the organisms involved.
31. Natural selection may have neutral consequences on the organisms involved.
32. Because natural selection preserves heritable characteristics, all species of living organisms have continued to have similar nucleic acid structure.
33. Variation plays no role in the survival of individual organisms in a population.
34. In the absence of variations, individuals in a population will not become extinct when vast changes occur in the environment.
35. Changes in allele frequencies may result from natural selection, migration, genetic drift, or mutation.
36. Adaptation as a proximate change is the immediate physiological change in an individual organism in response to change in the environment.
37. Adaptation as an ultimate change is a gradual processes allowing heritable traits to be passed on to next generations.
38. The fact that there is less chance of finding relatively complex fossils in the older sedimentary rock strata does not support the theory of evolution.
39. The theory of evolution by natural selection provides a logical explanation of the similarities and differences observed among living organisms.
40. A scientifically literate individual displays the scientific "habit of mind" employing scientific reasoning to all aspects of nature.
Part C: Concepts Related to Homologous and Analogous Anatomical Features

41. Systematic classification of living organisms makes more sense when their evolutionary history are considered.........................1 2 3 4

42. Convergent evolution is responsible for similarities in functional (analogous) features among organisms living in the same environment...................1 2 3 4

43. Divergent evolution is responsible for similarities in structural (homologous) features among living organisms.................................1 2 3 4

44. Typological explanations are adequate for the structural similarities and differences observed among living organisms.................................1 2 3 4

45. Teleological explanations are adequate for the structural similarities and differences observed among living organisms.................................1 2 3 4

46. Understanding the history of biology and modes of thought used by founder biologists enhances our understanding of biology as a process of knowing.........................1 2 3 4

47. Meaningful understanding of biological knowledge is not inherently based on an understanding of the historical nature of biology.........................1 2 3 4

48. Meaningful understanding of biology is not inherently based on evidence that supports characteristics observed among living organisms.........................1 2 3 4

49. Homologous features are found in two or more taxa or species and are traceable to similar features in intermediate ancestors.........................1 2 3 4

50. Analogous features in two or more taxa or species perform similar functions but are not traceable to similar features in their intermediate ancestors.........................1 2 3 4

51. An understanding of evolutionary biology does not enhance one's ability to understand comparative anatomy, physiology, and biochemistry.................................1 2 3 4
52. Knowledge of microevolutionary and macroevolutionary changes are not complementary to meaningful understanding of biology
53. Homologous and analogous anatomical features observed in two or more species of organisms are products of evolutionary processes
54. Most if not all concepts and processes in biology make more sense "in the light of evolution"
55. "The probability that natural selection could build an anatomical structure as complex as an eye is equal to the probability that a hurricane could pass through a junkyard and build a 747"
56. Competition plays no role in the evolutionary process
57. Scientific knowledge usually surprises us if we discover that our world is not as we perceive it to be
58. Scientific knowledge rarely troubles us if we discover that our world is not as we perceive it to be
59. Evidence and theories drive biological research
60. Scientific knowledge sometimes forces us to discard beliefs we have long held about the grant scheme of nature

Note:

Test item #9. "What" questions in biological sciences research are used to identify the concept, principle, process, living organism or biological phenomenon in question.

Test item #10. "How" questions refer to the mechanism and scientific explanation of the biological phenomenon in question.

Test item #11. "Why" questions refer to logical reasons for the existence or occurrence of a natural or biological phenomenon.
APPENDIX E: STANDARDIZED INTERVIEW QUESTIONS

Part 1: Science, Biology and Family Background

1. In addition to the information you have provided on your release form, would you like to tell me a little bit about yourself?

2. What are you majoring in at LSU?

3. Are there any scientists in your family?

4. What biology courses did you take in high school?

5. What biology courses are you taking or have completed at LSU?

Part 2: Conceptions of Science and Biology

1. Would you like to explain what science is?

2. How is science different from the other subjects you have studied?

3. How is biology different from the other science subjects?

4. What do you think the place of biology is in understanding the natural world?

(This section of the student interviews complemented students' responses to test items 1, 2, 3, 4, 5, and 6 of the NOBKS questionnaire)

Part 3: Origin and Nature of Change in Biological Processes

1. Do you think living organisms were created the way they appear today by special creation? (Complementary to test item 12 of the NOBKS questionnaire).

2. How different do you think living organisms are from non-living things? (Complementary to test items 13, 14, 15, 16, and 17 of the NOBKS questionnaire).

3. What role does chance play in changes observed in living? (related to test item 18 of the NOBKS questionnaire).
Part 4: Mutation and Natural Selection

1. Explain in your own words the terms genetic mutation and evolution by natural selection?

2. Explain the mechanism of natural selection? (test items 26 and 27).

3. What are the consequences of natural selection? (Complementary to test items 28, 29, 30, 31, 32 of the NOBKS questionnaire)

4. How is natural selection different from mutation? (Complementary to test item 35 of the NOBKS questionnaire).

5. In Table 19 provided below, indicate with a check (V) the level of organization at which you think natural selection and mutation occur in living organisms?

<table>
<thead>
<tr>
<th>Biological level of organization</th>
<th>Mutation</th>
<th>Natural selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tissue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community/Ecosystem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biosphere/Ecosphere</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part 5: Proximate and Ultimate Adaptive Processes

Use the graph of mosquito population provided in Figure 23 to answer the following questions. The graph shows how the mosquito population responds to an insecticide spray DDT during a summer spray program instituted on an isolated tropical island (complementary to test items 26, 27, 28, 29, 30, 31, 33, 34, and 35 of the NOBKS questionnaire).
Figure 23: Graph of Mosquito Populations on a Tropical Island During a Summer Spray Program.

1. What are the most probable reasons for the deceasing effectiveness of the insecticide as the summer progressed?

2. What process(es) are chiefly responsible for the change in section III of the graph?

3. What role did chance play in the process(es) you have identified?

Part 6: Natural Selection and “Biological Fitness”

1. Table 20 describes four male lions in a large population of lions. The four males are named Ben, George, Sandy and Sporty. Ben usually has the greatest number of females in his den. George is the largest of the four, he is healthy and strong. Sport is quite agile, when his den was destroyed by fire he quickly moved his pride to a new location. Sandy was killed by an infection which spread from a cut in his foot. Use the table below which describes population of male lions to answer the following questions about biological fitness (Complementary to same test items as in interview questions in Part 5).
Table 20: Natural Selection and Biological Fitness Among Male Lions

<table>
<thead>
<tr>
<th>Physical Traits</th>
<th>Ben</th>
<th>George</th>
<th>Sporty</th>
<th>Sandy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body length (ft)</td>
<td>8.5</td>
<td>10</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Body weight (lbs)</td>
<td>160</td>
<td>200</td>
<td>175</td>
<td>170</td>
</tr>
<tr>
<td># of cubs per year</td>
<td>25</td>
<td>19</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Avg # cubs surviving per year</td>
<td>18</td>
<td>15</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Age at death(years)</td>
<td>16</td>
<td>13</td>
<td>12</td>
<td>9</td>
</tr>
</tbody>
</table>

a) Which of the four male lions described is most biologically "fit" in this generation of lions? Why?

b) Which one was least biologically "fit" and why?

c) How did you select or determine biological fitness among the males in this population of lions?

2. A species of cave salamanders are blind because their eyes are nonfunctional. Analysis by biologists reveals that they still posses genetic and anatomical features suggestive of having had sighted ancestors. Would you say these blind salamanders are more fit than their blind ancestors?

Part 7: Evolution and Speciation

1. What is meant by a species of living organisms?

2. Do you think understanding of evolution is important for understanding speciation?

3. Referring to the blind salamanders described during interview 6 earlier. How do you explain the evolution of the blind species of salamanders from their sighted ancestors?
4. If these present blind salamanders are removed from dark caves and reared in a well-lit laboratory environment, do you think they will evolve sight and begin to see like their ancestors did?

5. What factors do you consider in your prediction about the evolution of sight in these salamanders?

**Part 8: Evolutionary Model 1**

Systematists use similarity in genetic and morphological features to classify species of living organisms. Comparative anatomists consider both anatomical similarities and differences to reconstruct the phylogenetic history of living organisms. Use the information provided on the following four hypothetical invertebrate organisms to complete the phylogenetic tree (phylogram) below.

![Phylogenetic Tree Diagram]

**Figure 24: Morphological Characteristics of Four Hypothetical Invertebrate Species**

Which of the two taxa above are most closely related and which ones are most distantly related? (Explain your written responses verbally)
Part 9: Evolutionary Model 2

1. Suppose you were able to dissect five vertebrate species including a human cadaver to expose and identify the segments present in their gastrointestinal tracts. The figure provided below shows what the gastrointestinal tracts would look like.

Figure 25: Comparative Anatomy (Morphology) of the Gastrointestinal System of Five Domestic Vertebrate Species

2. Using the information on the figure above, construct a phylogenetic tree (phylogram) to show the evolutionary relationships among the five vertebrate species.

3. Which of the vertebrate species would you consider most closely related and which ones are most distantly related? (Explain your answers verbally).
Part 10: Evolution, Scientific and Biological Literacy

1. How would you describe a scientifically literate person?

2. What is your opinion about the importance and usefulness of biological evolution to biologists in their everyday field or laboratory work or research?

3. Suppose you were a medical practitioner at the time that an experimental HIV/AIDS vaccine had been developed and approved by the U.S Department of Food and Drug Administration (FDA) and the Center for Disease Control in Atlanta, Georgia for experimental use in AIDS/HIV infected human patients. You have also learned that the vaccine was developed in a highly reputable research laboratory using attenuated viral DNA that had been cultivated on rhesus monkey cell lines infected with the AIDS/HIV virus. Comprehensive testing of the vaccine (including safety tests) have revealed that the vaccine is effective in preventing new cases and the spread of the AIDS/HIV virus among human patients already infected with the virus.
   (a) Would you consider using this vaccine in your medical practice?
   (b) Explain why? (Provide all the medical, ethical, or value-related reasons for your choice).
VITA

Gloria Millie Apio Ameny was born on April 29, 1961 in Lira, located in the northern region of Uganda. She is the last child of Dr. John Yekosafati Odomoch and Mrs. Terofaina Odomoch. She spent many of her early school holidays on a large mixed farm owned by her parents. These surroundings and her later training in veterinary medicine prompted her interests in understanding relationships among living organisms, particularly, vertebrate animals.

She graduated from St. Katherine's Secondary School in 1977, and from Namasagali College in 1979. She attended Makerere University, School of Veterinary Medicine, Makerere University, Kampala, Uganda where she received a bachelor of veterinary medicine degree in August 1986. After completing her internship in 1987, she worked as a registered Veterinary Officer and the Seminar Coordinator for the Uganda Dairy Development Project. In 1990 she left her country Uganda to come to the United States.

While in the United States, she worked as a Research Associate at the Louisiana State University School of Veterinary Medicine until 1992 when she began to pursue a graduate degree at Louisiana State University. She received a master of science degree in Dairy Science in May 1994. In the fall semester of 1995 she joined the Department of Curriculum and Instruction to begin working towards a doctoral degree. During her doctoral program she worked as Graduate Teaching Assistant at the Center for Scientific and Mathematical Literacy. She expects to receive the degree of Doctor of Philosophy in Science Education in May of 1999.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate:   Gloria M. Ameny

Major Field:  Curriculum and Instruction

Title of Dissertation:  College Biology Students' Conceptions Related to the Nature of Biological Knowledge: Implications for Conceptual Change

Approved:

[Signatures]

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

March 22, 1999