Influences of Teleological and Lamarckian Thinking on Student Understanding of Natural Selection

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Abstract: Previous research has demonstrated creationist, Lamarckian, and teleological reasoning in high school and college students. These lines of thinking conflict with the Darwinian notion of natural selection, which serves as the primary catalyst for biological evolution. The current study assessed evolutionary conceptions in non-science majors, freshman biology/environmental science majors, and upper-level biology majors at a small liberal arts college. Results indicate that, prior to instruction, both non-science majors and upper-level biology majors appear to rely heavily on teleological reasoning to explain changes in gene frequencies over time. Instruction that incorporated historical context and avoided teleological language improved student understanding of Darwin's concept of natural selection.

Keywords: creationism, Lamarck, teleology, natural selection

Introduction

The concept of evolution by natural selection is central to understanding biology. While the *proximate*, or functional, aspects of biological inquiry can be utilized to explain "how" a macromolecule, organ, or individual performs, an *ultimate*, or evolutionary, way of thinking is necessary to investigate and understand "why." The theory of evolution provides a unifying framework within which many diverse concepts are integrated and explained.

Biological evolution can be defined as changes in the gene pool of a population over time or, as Darwin described it, descent with modification. The concept of natural selection provides a mechanism to explain the evolutionary process and is based on two suppositions: 1) there is considerable variation among individuals within a population, and 2) some variations are advantageous in terms of survival. Individuals possessing these advantageous characteristics are more likely to survive and successfully reproduce. Eventually, organisms possessing the favorable characteristics make up a greater proportion of the population.

Studies of high school (Settlage, 1994; Demastes *et al*., 1995), college (Bishop and Anderson, 1990; Anderson *et al*., 2002), and medical school (Brumby, 1984) populations indicate that misconceptions concerning natural selection are quite prevalent. Student misunderstandings about the mechanism of biological evolution often stem from common erroneous assumptions: 1) changes in traits are attributed to use or disuse of anatomical features, 2) changes in traits are attributed to a goal- or need-directed process, and/or 3) no role is assigned to variation within populations or differences in reproductive success. A poor understanding of the basic concepts of genetics, as well as an inability to distinguish adaptation at species and individual levels, may be partly responsible for these misconceptions (Hallden, 1988).

In 1809, 50 years before Darwin described the process of natural selection, French zoologist Jean-Baptiste Lamarck proposed *la marche de la nature*, a single straight line of evolutionary progress. Lamarck's explanation of species-specific adaptations to local environments was based on the strengthening of body parts through repeated use, or their weakening as a response to disuse. These acquired traits, according to Lamarck, could be passed on to the next generation. Although it is now well established that acquired characteristics are not inherited and do not contribute to biological evolution, students commonly use a Lamarckian approach to explain changes in organisms over time (Settlage, 1994; Crow, 2004).

The Greek word *telos* means end or goal. *Teleological* means end- or goal-directed. A teleological, or goal-directed, description of a biological structure or function implies that any benefit derived from the structure or function is a sufficient reason for its existence, negating the impact of variation. While teleological reasoning may sometimes help students in organizing facts and grasping natural phenomena, the belief that organisms adapt to their environments because they "need to" undermines Darwin's descent with modification by attributing goal-directed properties to the somewhat random process of natural selection.

Teleological evolution implies that change is directed by some outside agent. Even if students do not consider a supernatural creator as a governing factor, they may still consider evolution as being directed by an outside agent such as "nature." Natural selection, to students with this perspective, is a process by which nature selects individuals who are in need to become beneficiaries of helpful changes (Greene, 1990).

Research studies concerning students' conceptions of evolution and natural selection report a limited ability of students to solve problems in Darwinian terms (Jimenez, 1992; Settlage, 1994; Demastes *et al*., 1995). Specifically, they fail to acknowledge the impact of population variation on changes in gene frequency. One possible reason for these difficulties is the influence of inaccurate conceptions of biological evolution. Teleological thinking, in particular, can lead to considerable misinterpretations of evolutionary theory (Greene, 1990). According to Lawson and Weser (1990), even the brightest students may hold naive conceptions concerning certain areas of science. However, those beliefs may be changed when alternate ideas are advanced, especially when evidence and/or arguments are examined to support or refute the deduced consequences of the alternatives.

Conceptual understanding is influenced by the integration of new knowledge with preexisting attitudes and beliefs. Some students may separate the understanding of the theory of evolution from any religious beliefs they might have, whereas others may see evolution and religion as opposing forces and reject evolutionary concepts outright (Smith *et al*., 1995; Dagher and BouJaoude, 1997; Sinatra *et al*., 2003). Lamarckian or teleological thinking would not be an issue with the latter students. It is possible that no amount of instruction, regardless of the strategy, would be effective in changing such rigid, faith-based beliefs (Sinclair and Baldwin, 1996).

The current study assessed understanding of natural selection by students with very different interests and scientific backgrounds. It was hypothesized that non-science majors and freshman biology/environmental science majors would initially express common evolutionary misconceptions more frequently than junior and senior biology majors. Furthermore, it was predicted that all groups would improve their comprehension of evolutionary mechanisms following instruction.

Methods

The current study involved students enrolled at Davis & Elkins College, a private, four-year liberal arts school that stresses small class size and strong faculty-student interaction. BIOL 100 (Basic Biology) is a one-semester survey of basic biological principles, designed to fulfill a general education requirement for non-science majors. BIOL 102 (Principles of Biology II) is the second half of a two-semester sequence designed for first-year students majoring in biology or environmental science. In BIOL 102, ecology, evolution, and biodiversity are emphasized. BIOL 305 (Evolution) is a capstone course for biology majors. The course focuses on the evidence, mechanisms, and genetics of organic evolution. Student understanding of evolution by natural selection was assessed in two sections of BIOL 100 (Fall 2004 and 2005), two sections of BIOL 102 (Spring 2005 and 2006), and one section of BIOL 305 (Fall 2005).

With the exception of the Fall 2005 section of BIOL 100, which was taught by author S.K.S., all courses were taught by author M.L.M. To ensure comparable assessment of BIOL 100 students, the authors collaborated to create a standard format for organizing content presentation. In all courses, lecture outlines and textbook figures were presented via Microsoft PowerPoint. Students had access to all PowerPoint slides and were encouraged to actively participate in the discussion of content. Questions were frequently asked to determine the extent to which students were following the lecture material.

While only two 50-minute and two 75-minute class periods were devoted exclusively to the topic of evolution in BIOL 100 and BIOL 102, respectively, the concept of natural selection was a recurring theme in both courses. When misconceptions about natural selection were encountered, the instructors provided clear and concise arguments to challenge them, while offering simple, understandable evidence to support legitimate scientific notions. Laboratory activities and/or problem solving sessions dedicated to promoting conceptual change were utilized in all courses to help students recognize the inadequacy of faulty preconceptions, while providing support for accurate views of biological evolution. For example, various eating utensils were employed in BIOL 100 to demonstrate differential success in capturing prey (in this case, beans), colored beads were utilized in BIOL 102 to illustrate Hardy-Weinberg equilibrium, and a collection of nuts and bolts provided the basis for a laboratory activity in phylogenetic analysis for BIOL 305 students. Furthermore, in an attempt to promote students' conceptual change from Lamarckian to Darwinian, the conflicting perspectives were placed in historical context to demonstrate the self-correcting nature of science. Finally, the use of teleological language during instruction was monitored carefully. Suggesting that organisms undergo particular adaptations to ensure survival was avoided. For example, statements like "The cheetah,in an effort to keep up with increasingly fast prey species, has evolved a remarkable ability to

run at very high speeds for a short period of time" or "The giraffe's neck has gradually gotten longer to allow access to food sources far from the ground" would have created the false impression that organisms adapt according to their needs. While such statements may have helped students to grasp particular aspects of evolutionary biology, they would almost certainly have facilitated misconceptions.

During the first week of each course, prior to any discussion of the mechanisms of biological evolution, students completed a 10-question, multiple-choice survey (Figure 1, appended at end of article). Questions 2, 3, 5, 6, 8, and 10 specifically addressed the concept of natural selection. For each of these six questions, four possible answers were provided to represent the following categories: Lamarckian, teleological, creationist, and Darwinian. Students received scores in each of the four categories. For example, if a student selected four teleological responses and two Darwinian responses, he/she would receive the following scores: Lamarckian = 0%; teleological = 67%; creationist = 0%; Darwinian = 33%. Thirty-four BIOL 100 students, 20 BIOL 102 students, and four BIOL 305 students were recruited to take the pre-test. Toward the end of the semester, after discussions and activities related to natural selection had been completed, students took the survey again. Participating students numbered 31, 18, and four for the BIOL 100, BIOL 102, and BIOL 305 post-tests, respectively.

Two-sample *t* tests were used to compare group means. All *t* tests were two-tailed, and an alpha level of $p<0.05$ was considered statistically significant.

Results

For BIOL 100 students, mean Lamarckian, teleological, and Darwinian scores were significantly higher than creationist scores on both pre- and post-tests. Furthermore, pre-test teleological scores (46.6%) were significantly higher than pre-test Darwinian scores (21%), and pre-test Darwinian scores were significantly lower than post-test Darwinian scores (43%; Figure 2).

For BIOL 102 students, mean Lamarckian, teleological, and Darwinian scores were significantly higher than creationist scores on both pre- and post-tests (Figure 3). When the BIOL 100 and BIOL 102 classes were compared to each other, no significant differences existed between the two groups in any of the categories on either the pre-test or post-test.

BIOL 305 students received Lamarckian, teleological, creationist, and Darwinian scores of 29%, 46%, 0%, and 25%, respectively, on the pre-test. Post-test scores were 8.3%, 25%, 0%, and 66.7% in the Lamarckian, teleological, creationist, and Darwinian categories, respectively (Figure 4). Since only four students were enrolled in BIOL 305 in the fall of 2005, a statistical analysis was inappropriate.

FIG 1. Natural Selection Survey.

1. What is a scientific theory?
    a. A personal opinion regarding a specific scientific topic
    b. An educated guess about the nature of a natural phenomenon
    c. A well-supported explanation of a natural phenomenon, generally accepted by the scientific community
    d. A testable hypothesis, generated in response to a scientific observation

2. Considering the normal vision of their ancestors, how do you explain the non-functional eyes of the cave salamander?
    a. The salamanders had to adapt to darkness in order to survive. Because vision was no longer needed, subsequent generations of salamanders had non-functional eyes.
    b. The first cave salamanders used their eyes less and less. Consequently, their offspring inherited non-functional eyes.
    c. There were varying degrees of eye function in the original salamander population. Individuals emphasizing vision as a sensory mechanism may have been unable to survive and reproduce.
    d. The cave salamander was created to be perfectly adapted to its environment.

3. If their distant ancestors could only achieve speeds between 20 and 30 miles per hour, how do you explain the ability of modern cheetahs to run at speeds in excess of 60 miles per hour for short periods of time?
    a. As the cheetahs used their legs more and more to chase prey, they developed strong sprinting muscles. As a result, their offspring inherited the ability to run at high speeds.
    b. The cheetahs had to adapt to capture fast-moving prey. Because speed was needed for survival, later generations developed streamlined, muscular bodies.
    c. There were a variety of body types in the original cheetah population. Individuals possessing the musculature necessary for short bursts of speed may have been better equipped to survive and reproduce.
    d. Cheetahs, and their prey, were created to run at high speeds.

4. Which of the following is <u>not</u> a product of artificial selection?
    a. African elephants
    b. German shepherds
    c. Red delicious apples
    d. Genetically-modified corn

5. Which of the following is the foundation of Darwin's concept of natural selection?
    a. There is always variation among individuals in a population.
    b. During the life of an individual, environmental pressures bring about permanent changes in the body. Those changes can then be passed on to future generations.
    c. All living organisms are exactly the same as they were when they were originally created.
    d. Organisms adapt according to their needs.

6. How do you explain the fact that some bacterial infections are now resistant to the antibiotics that were developed to treat them?
    a. As a result of mutation, there is a great deal of variation within a bacterial population. Those strong enough to survive the initial antibiotic treatment will reproduce more, and resistance will become more prominent in the population.
    b. Initially, bacterial strains were caught off-guard by antibiotics. Then, they began using more of their natural defenses to resist antibiotic treatments. Now, as a result, current generations of bacteria have acquired resistance to antibiotics.
    c. The bacteria's goal is survival. To ensure survival of the species, resistance to antibiotics was needed. Consequently, bacterial populations have mutated to obtain more and more resistance over the years.
    d. Bacteria were created to be antibiotic-resistant.

7. Can you believe in God and still accept the theory of evolution?
    a. No

b. Yes

8. When it was first developed to treat HIV infection, the drug AZT was very effective at decreasing viral levels in the blood. However, the effect was only temporary, and HIV levels eventually became elevated again. How do you explain this?
    a. The virus was created with a mechanism to resist pharmacological treatment.
    b. The virus gains resistance as it is continuously exposed to AZT. During the asymptomatic phase of infection, the virus will reproduce, and subsequent generations of viruses will inherit the resistance.
    c. As the virus mutates during the asymptomatic phase of the infection, a variety of viral antigens are produced. Viruses bearing antigens unrecognizable by the host's immune system will propagate rapidly.
    d. To survive, the virus needs to resist the effects of the drug. During the prolonged, asymptomatic phase of infection, the virus mutates to meet its needs.

9. If humans evolved from apes, why are apes still around?
    a. The apes that were well-adapted to their specific environments maintained their ape-like characteristics. Other populations of apes, under different environmental pressures, evolved into humans in order to survive.
    b. Humans did not evolve from apes. Each species was created separately.
    c. Humans did not evolve from apes. Evidence suggests that they shared a common ancestor, a species that no longer exists.
    d. Evolution is a gradual, progressive process. Eventually, all apes will evolve into humans.

10. Some plants produce chemical toxins that make them distasteful to herbivores. If ancestral plants were unable to produce toxins, how did this mechanism develop?
    a. The plants had to adapt to the presence of herbivores in order to survive. The production of chemical toxins represents an adaptation of necessity.
    b. Initially, the plants may have produced no toxins. However, at some point, they began to actively synthesize toxic chemicals. After that, subsequent generations of plants would have inherited the ability to produce toxins.
    c. Initially, there was probably a great deal of variation in the plant population. Those plants that were able to synthesize toxic chemicals were more likely to survive and reproduce.
    d. The plants have maintained an ability to synthesize toxins since their creation.

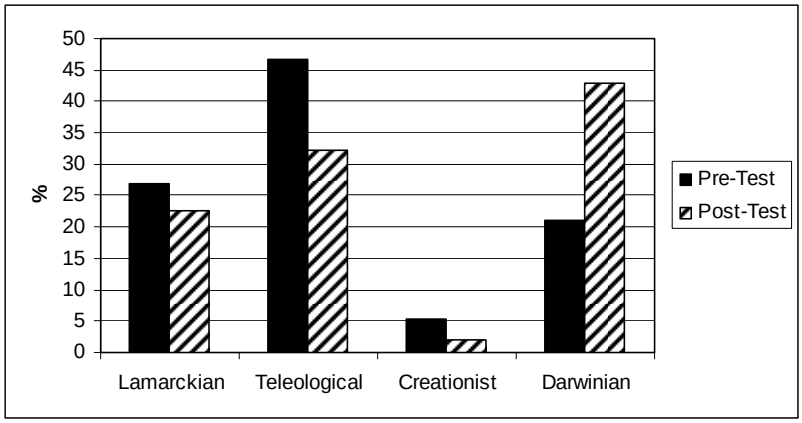

FIG 2. Mean BIOL 100 Scores. Mean Lamarckian, teleological, and Darwinian scores were significantly higher than creationist scores on both pre- and post-tests. Pre-test teleological scores were significantly higher than pre-test Darwinian scores. *Post-test Darwinian scores were significantly higher than pre-test Darwinian scores.

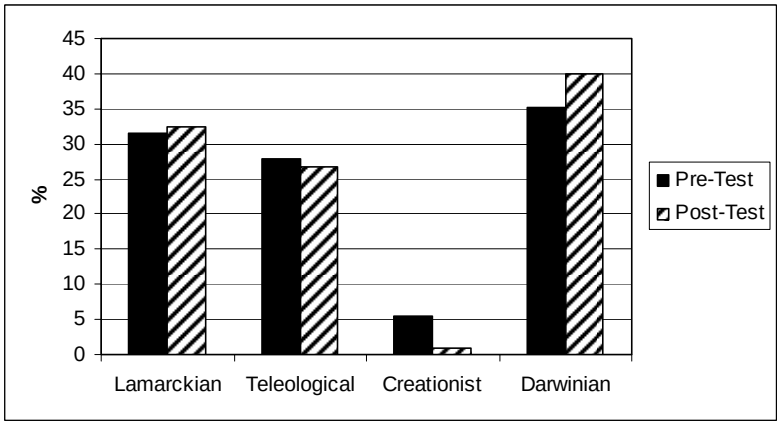

FIG 3. Mean BIOL 102 Scores. Mean Lamarckian, teleological, and Darwinian scores were significantly higher than creationist scores on both pre- and post-tests.

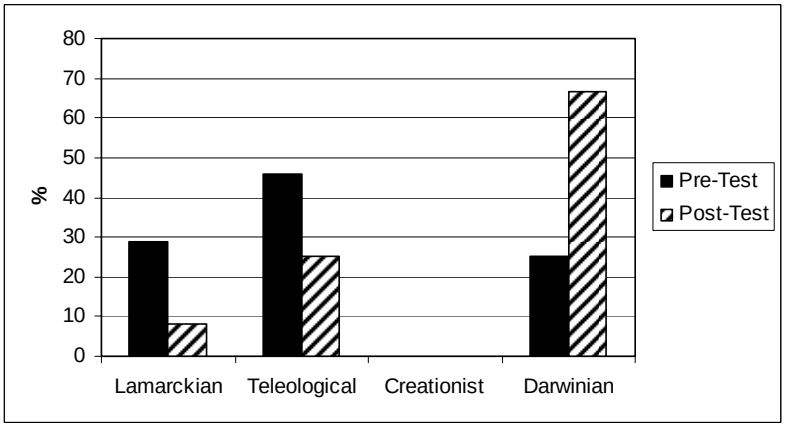

FIG 4. Mean BIOL 305 Scores. Only four students completed the pre-and post-tests; a statistical analysis was not appropriate.

Discussion

Although previous research indicates that many students will reject evidence supporting the theory of evolution because they perceive a conflict with their religious beliefs (Smith *et al*., 1995; Dagher and BouJaoude, 1997; Sinatra *et al*., 2003), the present study demonstrates an overall acceptance of the theory (but not an understanding of the mechanism behind it). Creationist scores were dramatically lower than other category scores in each of the three groups (Figures 2, 3, and 4).

According to Jensen and Finley (1996), the most common evolutionary misconceptions expressed by non-science majors are related to a teleological way of thinking. Moreover, Brumby (1984) found that the primary fallacy in first-year medical students' conceptions of biological evolution is the attribution of a need-directed process to species adaptation. Finally, a study by Richardson (1990) demonstrates that high school students, non-science majors, allied health majors, and medical students express a strong tendency to think of body functions in teleological terms. In the current study, teleological reasoning was significantly more prominent than a Darwinian line of reasoning in BIOL 100 students on the pre-test (Figure 2); a similar, but non-significant, trend was seen in the BIOL 305 students (Figure 4). Research by Keleman (2003) suggests that teleological reasoning develops during childhood. It appears that children use teleology to explain functions of both living and non-living natural phenomena (clouds, rocks, etc.). In contrast, adults seem to limit their teleological explanations to biological phenomena. The notion that biological structures have developed to serve a specific goal or need must be very deeply rooted, as even junior and senior biology majors fall into this line of thinking.

Previous studies on populations of high school students (Demastes *et al*., 1995) and college students majoring in non-science disciplines (Bishop and Anderson, 1990; Demastes *et al*., 1995) assessed curricular strategies similar to the ones used in BIOL 100 and BIOL 102 in the current study. In the previous studies, approximately one week of explicit instruction on the topic of evolution, references to the concept of natural selection throughout the course, relevant laboratory activities, and problem solving sessions designed to confront misconceptions resulted in moderate improvements in understanding of Darwinian concepts. Sheppard and Prischmann (2003) found that the use of an historical perspective of evolution in an introductory biology course for non-science majors allowed presentation of the topic in a less threatening, yet more comprehensive, manner. Furthermore, Jensen and Finley (1996) found success in a non-majors introductory biology course by approaching the topic of natural selection through historically-based discussion in conjunction with relevant problem solving sessions. The current study reports a statistically significant increase in post-test Darwinian scores for BIOL 100 students (Figure 2), and post-test Darwinian scores for BIOL 305 students improved by more than 40% (Figure 4).

A 2003 study by Sandoval and Morrison indicated that high school students generally viewed science as a search for evidence to provide legitimate explanations for phenomena associated with the natural world. However, when asked specific questions about the nature of science, including the concept of natural selection, students' responses were often inconsistent with their overall view of science. The current study illustrates similar inconsistencies. While participating students seemed to accept evolutionary theory as legitimate, they inconsistently designated Lamarckian, teleological, or Darwinian mechanisms as the driving force behind evolutionary change. BIOL 102 students, in particular, epitomized inconsistency. For these students, there were no significant differences between Lamarckian, teleological, and Darwinian scores on pre- or post-tests (Figure 3).

In all three classes we examined, creationist scores were dramatically lower than other category scores. It is possible that students steered away from the word "creation" because they assumed it to be incongruent with a science curriculum. It is also possible that students were able to keep their religious beliefs separate from the science of evolutionary theory. For survey question #7 (*Can you believe in God and still accept the theory of evolution?*), 80% of all participants responded "yes" on the pre-test, and 90% of all participants responded "yes" on the post-test.

In conclusion, the present study demonstrated inconsistencies in student responses to questions regarding the process of natural selection. While teleological responses were quite common prior to any instruction, post-test results indicated an increase in Darwinian responses from non-science majors and upper-level biology majors.

It is apparent that Darwinian reasoning is not intuitive. Many students will enter college with religious beliefs or reasoning strategies that conflict with the concept of natural selection. As indicated by the small sample of BIOL 305 students, even upper level biology majors can fall into a teleological mode of thinking. The theory of evolution is central to understanding biology. Perhaps the concept of natural selection should be even more ubiquitous in biology courses, for both majors and non-majors. If exposure to the concept is maximized, students may be more likely to set their default reasoning gauge to "Darwinian."

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