Using this Module to Overcome Critical Barriers

For many students in a beginning biology course, the naive conceptions described above are deeply ingrained. We have found that for such students even the best explanations are not enough. Replacing easy and familiar naive conceptions with more abstract biological conceptions is a difficult process, requiring sustained effort on the part of the student, corrective feedback from teachers, and many opportunities for practice and application.

The materials in this module are ones that we have developed, field-tested, and found to be useful in helping students to overcome the critical barriers described above. In addition to lecture materials providing clear explanations of evolution by natural selection (Section III), this module includes a diagnostic test that can be used as both a pretest and a posttest (Section II), laboratory activities (Section IV), and problem sets (Section V). Those materials can be used either independently or in combination, and they do not need to be used in any particular order, although the laboratory activities and problem sets are designed to be done after students have read or heard explanations of the relevant concepts. The materials are useful because they help instructors do three things that are essential for helping students to overcome critical barriers:

1. Diagnosis of student difficulties. The diagnostic test, the laboratory activities, and the problem set all contain questions designed to reveal how well students understand the biological conceptions of evolution by natural selection. The commentary for teachers describes specifically what each question is designed to reveal.

2. Creating dissatisfaction with naive conceptions. Many students enter our course expecting to memorize facts and definitions when we would like them to think scientifically. The activities in this module provide students with many opportunities to see that their present ways of explaining and predicting scientific phenomena do not work very well and to understand how their ideas need to be improved.

3. Providing opportunities for practice and application. The scientific conceptions described above are important because they explain many different phenomena in a satisfying way. The activities in this module help students to see the power of these conceptions by applying them to a variety of phenomena. Since the basic purposes of scientific theories are to explain and to predict, we feel that the questions asking students for explanations and predictions are especially important.

In short, the questions and activities in this module are designed as tools to help you, the instructor, help your students through the process of conceptual change. This module cannot substitute for your personal planning and judgment, but it can help you make your plans and judgments better informed and thus more effective.

II. Diagnostic Test and Commentary

This student test has been developed and tested over the course of several terms. It is designed to be given as a pretest and/or posttest. Most students should take about 15 minutes to complete it.

The primary purpose of this test is diagnostic; it enables instructors to assess student understanding of the process of natural selection when used as a pretest, and it allows instructors to monitor student progress when used as a posttest.

However, the value of this test goes beyond its diagnostic function. Since the test essentially poses problems for students to solve, it also allows students to practice their newly acquired scientific ideas. Many of our students are eager to take this test after subject coverage as a review for examinations.

The following left-hand pages contain the test as we have used it with our students. The right-hand pages contain a commentary explaining the purposes of each question and how student answers can be interpreted.

This test was designed and revised extensively to meet the objective of exposing student misconceptions. Your students' answers will probably be most revealing and useful if students do not take the test for a grade and if you ask them to try to describe how they think about the problem even when they do not know the correct scientific answer. The students' incorrect answers to these questions are often more interesting and revealing than their correct ones.

Evolution Diagnostic Test

1. Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run 20 miles per hour?

2. Cave salamanders are blind (they have eyes which are nonfunctional). How would a biologist explain how blind cave salamanders evolved from sighted ancestors?

Commentary: Questions 1 & 2

This pair of questions is intended to give students a chance to demonstrate their overall understanding of the process of natural selection and to allow instructors to assess this understanding. Since such open-ended questions are often difficult to interpret, it is suggested that instructors look for understanding of the three key ideas.

a. Reference to two separate influences on traits exhibited by a population: Random genetic changes leading to a change in the trait *quality* and environmental conditions influencing the survival and spread of existing traits (e.g., differential reproduction).

   The ideal answer would include reference to mutations resulting in appearance of the trait (for example: "a mutation resulted in a faster cheetah"), but student answers may not refer to mutation and still be basically correct as long as the answer *does not include reference to the environment* as affecting the quality of *the trait itself.*

   Students possessing naive conceptions tend to (a) make no differentiation between appearance and survival of a given trait and/or (b) include reference to only the environmental conditions as affecting traits. (examples: "Cheetahs needed to be fast because their prey was fast, so they evolved speed." "Cave salamanders adapted to the darkness of the cave by becoming blind." "Lack of need for and use of eyes resulted, over many years in blind salamanders.")

b. Recognition of the importance of differences between individuals in a given population.

   Ideal answers include explicit or implicit reference to difference in traits individuals possess (example: "*some* cheetahs were fast") and the differences in breeding success (example: "Blind salamanders produced more offspring").

   Students holding naive conceptions view evolution as occurring in all members of a population simultaneously. Their answers contain reference to the species as a *collective* (example: "*Cheetahs* gradually evolved speed)."

c. Evidence that the student understands that evolution of a given trait consists of spread (or decline) of that trait through the population over several generations. Such understanding may be explicit (example: "Each generation consisted of more fast cheetahs") or implied (example: "Only the blind salamanders reproduced and passed on the trait of blindness"). Students possessing a naive conception of the evolutionary process often imply that the quality of the trait changes with succeeding generations (example: "Over the years, cheetahs gradually got faster and faster").

   It is often interesting for instructors to compare individual students answers to these two questions. Students often are able to provide correct answers to the easy (cheetah) question, while falling back on their naive conceptions for the harder (blind cave salamanders) question. This indicates that, for such a student, the conversion from naive to scientific conceptions is, at best, incomplete.

3. For the following question, use the numbered statements listed and circle the number which most closely corresponds to what you understand.

   1 -- The statement on the left is the only correct statement.
   2 -- The statement on the left is more correct.
   3 -- Both statements are equally correct.
   4 -- The statement on the right is more correct.
   5 -- The statement on the right is the only correct statement.

   If neither statement represents your understanding, please explain.

   Ducks are aquatic birds. Their feet are webbed and this trait makes them fast swimmers. Biologists believe that ducks evolved from land birds which did not have webbed feet.

   a. The trait of webbed feet in ducks:

Appeared in ancestoral ducks because they lived in water and needed webbed feet to swim.	1 2 3 4 5	Appeared in ducks because of a chance mutation.

   Explain:

   b. While ducks were evolving webbed feet:

With each generation, most ducks had about the same amount of webbing on their feet as their parents.	1 2 3 4 5	With each generation most ducks had a tiny bit more webbing on their feet than their parents.

   Explain:

   c. If a population of ducks were forced to live in an environment where water for swimming was not available:

Many ducks would die because their feet were poorly adapted to this environment.	1 2 3 4 5	The ducks would gradually develop nonwebbed feet.

   Explain:

   d. The populations of ducks evolved webbed feet because:

The more successful ducks adapted to their aquatic environment.	1 2 3 4 5	The less successful ducks died without offspring.

   Explain:

3. This question focuses on the concept of change in traits over time. The form of this question is especially useful to instructors in assessing student belief in scientific versus naive conceptions. The question as a whole consists of a series of pairs of statements. One statement in each pair represents correct scientific understanding of natural selection, the other represents a common naive conception. Since students are not forced to make an either-or choice, the degree to which the scientific versus naive conception is accepted by students can be assessed.

a. Many students, although understanding and accepting the idea of random mutations, still believe that an environmentally imposed need for a trait will somehow (unspecified) influence the appearance of such a trait. The *idea* of this naive conception is perhaps more appealing (i.e., organisms evolve the traits they need) than the correct scientific conception (traits appear by chance), but millions of extinct species that did not evolve the traits they needed to survive bear witness to the error of the naive conception.

   In addition to believing that need influences *appearance* of traits, these students are probably not making a distinction between the causes of the appearance of traits, and the survival of traits over time (for which need *does* have an important influence).

b. Many students believe that the *quality* of the trait improves from one generation to the next. Such students often exhibit naive conceptions of the nature of the evolutionary process (i.e, evolution consists of gradual improvement of a trait). Even students who correctly understand that short-term evolution consists of the spread of traits through a population may still believe that the quality of the trait improves ever so slightly as it is passed from one generation to the next. Whether these students attribute this improvement to experiences of the parental generation is not clear. Certainly some students do. Others perhaps feel that traits just naturally "improve" with time.

c. This pair of statements address the same idea as 3a (i.e., whether "need" for a trait affects its appearance) but is asked in a different way. Since the statements specifically refer to a single population of ducks, students should recognize that the chances of a mutation to nonwebbed feet is very slim, and circle item #1 or 2.

d. In order to answer this question correctly, students will have to recognize: (a) that evolution consists of the spread of traits through a population, (b) the essential role individual differences in traits plays in differences in breeding sucess, (c) that the role the environment plays is only in determining the survival of a given trait.

4. A number of mosquito populations are today resistant to DDT, even though those species were not resistant to DDT when it was first introduced. Biologists believe that DDT resistance evolved in mosquitos because: (choose the best answer)

   a. Individual mosquitos built up an immunity to DDT ater being exposed to it.
   b. Mosquitos needed to be resistant to DDT in order to survive.
   c. A few mosquitos were probably resistant to DDT before it was ever used.
   d. Mosquitos learned to adapt to their environment.
   e. Other; please explain _____

   _____

5. Biologists often use the term "fitness" when speaking of evolution.

   Below are descriptions of four male lions. According to your understanding of evolution, which lion would biologists consider the "fittest"?

Name	George	Ben	Spot	Sandy
Size	10 feet 175 lbs	8 1/2 feet 160 lbs	9 feet 162 lbs	9 feet 160 lbs
Number of cubs fathered	19	25	20	20
Age of death	13 years	16 years	12 years	9 years
Number of cubs surviving to adulthood	15	14	14	19
Comments	George is very large, very healthy. The strongest lion	Ben has the greatest number of females in his harem.	When the area that Spot lived in was destroyed by fire, Spot was able to move his pride to a new area & change his feeding habits.	Sandy was killed by an infection resulting from a cut in his foot.

   The "fittest" lion is:

   a. George b. Ben c. Spot d. Sandy

   Explain your answer:

6. Do you believe the theory of evolution to be truthful? _____ Why or why not?

The way that the word "adapt" is used in the statement on the left refers to changes in individuals in response to environmental conditions. Students circling low numbers--1 or 2--are usually understanding evolution in a naive way, that is, that most or all individuals in the population as a whole respond to the environment (adapt) and this results in a change in the quality of a trait (naive "evolution") over time.

4. In order to correctly answer this question, students will have to reject the following naive conceptions:

   a. Evolutionary change results from individuals responding to environmental change. Students believing this tend to circle Item a, viewing the evolution of resistance as synonomous with the build up of immunity.

   b. Appearance of a given trait results from an environmentally imposed need for such a trait. Students holding this naive conception tend to circle Item b.

   c. Evolution results from individuals adapting in the common-usage sense (i.e., individuals responding to their environment). Students holding this naive conception tend to circle Item d. These students often misunderstand the term "adaptation" as used in the biological sense.

   In addition to rejecting the naive conceptions above, students answering correctly (Item c) usually recognize the importance of individual differences in traits to the evolutionary process. (i.e., some individuals were probably resistant).

   Item e (other; please explain) is included in the test to allow students who have multiple naive conceptions or naive conceptions combined with scientific conceptions to express their understanding. An example of this type is: "Both a and c, some were resistant, and the others built up immunity."

5. The purpose of this question is twofold: (a) to assess student understanding of the word "fitness" as used in evolutionary terminology and (b) to illustrate student understanding of evolution as a whole.

   Students operating within a naive definition of "fitness" are likely to circle George because he is described as big, healthy, and strong.

   Students understanding the evolutionary process as a result of individuals "adapting" (i.e., changing in response to) will tend to circle Spot because he was able to move his pride and home when conditions changed.

   Students who understand that fitness refers to breeding success or length of life, but fail to understand the importance of offspring survival, will tend to circle Ben, either because; "He lived the longest," "He had the greatest number of females in his pride," or "He produced the most offspring."

Ideal answers should explain that Sandy was fittest because he left the greatest number of surviving offspring.

6. This question is included in the student test for two reasons. First, it gives instructors a feeling for the class composition of beliefs on the controversial question of evolution. Second, answers to the question; "why or why not" often bring forth basic student misunderstandings of evolution and natural selection.

   While we do not feel it is appropriate to try to convert students' beliefs on the subject of evolution, we do feel students should be expected to understand the concepts. Only from such understanding can informed decisions be made.