DOCUMENT RESUME

ED 272 383 SE 046 876

AUTHOR	Bishop, Beth A.; Anderson, Charles W.
TITLE	Evolution by Natural Selection: A Teaching Module. Occasional Paper No. 91.
INSTITUTION	Michigan State Univ., East Lansing. Inst. for Research on Teaching.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	Jun 86
CONTRACT	400-81-0014
NOTE	58p.; For other teaching modules in this series, see SE 046 875 and SE 046 877.
AVAILABLE FROM	Institute for Research on Teaching, College of Education, Michigan State University, 252 Erickson Hall, East Lansing, MI 48824-1034 ($5.50).
PUB TYPE	Guides - Classroom Use - Guides (For Teachers) (052) -- Tests/Evaluation Instruments (160)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	*College Science; Ecology; *Evolution; Genetics; Higher Education; Learning Modules; *Misconceptions; Preservice Teacher Education; Problem Solving; *Science Activities; Science Education; Science Experiments; Science Instruction; Secondary Education; *Secondary School Science
IDENTIFIERS	Alternative Conceptions; *Natural Selection

ABSTRACT

Designed to address the major conceptual problems associated with evolution and variation and survival in populations, this module can be used with high school students or college nonscience majors including those in elementary education. It is one in a series developed by the project "Overcoming Critical Barriers to Learning in Nonmajors' Science Courses." The materials offer guidance to teachers in diagnosing student deficiencies, in creating dissatisfaction with misconceptions, and in providing opportunities for application and practice. This module contains: (1) an introduction (specifying the critical barriers to understanding natural selection and explaining how to use the module to overcome these barriers); (2) diagnostic test and commentary (designed to be used as a pretest and/or posttest); (3) materials for lecture or discussion with commentary (consisting of a series of copy-ready masters for use as overhead transparencies and student handouts on evolution by natural selection); (4) laboratory activities and commentary (including a lesson on the evolution of "bead bugs"); and (5) problem sets (addressing the value of variation of traits to the process of natural selection and the nature of adaptive traits). All instructional materials for the students are juxtaposed with instructor commentaries. (ML)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

Occasional Paper No. 91

EVOLUTION BY NATURAL SELECTION: A TEACHING MODULE

Beth A. Bishop and Charles W. Anderson

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it
Minor changes have been made to improve reproduction quality
Points of view or opinions stated in this document do not necessarily represent official OERI position or policy

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
Charles W. Anderson
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SE 046 876

ERIC

Occasional Paper No. 91

EVOLUTION BY NATURAL SELECTION: A TEACHING MODULE

Beth A. Bishop and Charles W. Anderson

Published By

The Institute for Research on Teaching
^52 Erickson Hall
Michigan State University
East Lansing, Michigan 48824-1034

June 1986

Funding for this project was provided by the Fund for the Improvement of Postsecondary Education, United States Department of Education, Grant Number G00 830 2727. The contents of this module do not necessarily reflect the position, policy, or endorsement of the Fund for the Improvement of Postsecondary Education.

This work is sponsored in part by the Institute for Research on Teaching, College of Education, Michigan State University. The Institute for Research on Teaching is funded primarily by the Office of Educational Research and Improvement, United States Department of Education. The opinions expressed in this publication do not necessarily reflect the position, policy, or endorsement of the Office or the Department. (Contract No. 400-81-0014)

Institute for Research on Teaching

The **Institute for Research on Teaching** was founded at Michigan State University (MSU) in 1976 by the National Institute of Education. Following a nationwide competition in 1981, the NIE awarded a second five-year contract to MSU. Funding is also received from other agencies and foundations for individual research projects.

The IRT conducts major research projects aimed at improving classroom teaching, including studies of classroom management strategies, student socialization, the diagnosis and remediation of reading difficulties, and teacher education. IRT researchers are also examining the teaching of specific school subjects such as reading, writing, general mathematics, and science and are seeking to understand how factors outside the classroom affect teacher decision making.

Researchers from such diverse disciplines as educational psychology, anthropology, sociology, and philosophy cooperate in conducting IRT research. They join forces with public school teachers who work at the IRT as half-time collaborators in research, helping to design and plan studies, collect data, analyze and interpret results, and disseminate findings.

The IRT publishes research reports, occasional papers, conference proceedings, a newsletter for practitioners, and lists and catalogs of IRT publications. For more information, to receive a list or catalog, and/or to be placed on the IRT mailing list to receive the newsletter, please write to the IRT Editor, Institute for Research on Teaching, 252 Erickson Hall, Michigan State University, East Lansing, Michigan 48824-1034.

Co-Directors: Jere E. Brophy and Andrew C. Porter

Associate Directors: Judith E. Lanier and Richard S. Prawat

Editorial Staff
Editor: Sandra Gross
Assistant Editor: Patricia Nischan

Abstract

This module is one in a series developed by the project Overcoming Critical Barriers to Learning in Nonmajors' Science Courses. Each module is self-contained and addresses a specific topic in the physical and biological sciences: respiration and photosynthesis, light, heat and temperature, and ecology. The modules are appropriate for use with high school students or college nonscience majors including those in elementary education.

This module on evolution by natural selection is arranged with materials for the instructor on one page juxtaposed by those for the students. A short introductory essay describes the major conceptual problems found among students: origin and survival of new traits in population, role of variation within population, evolution as the changing proportion of individuals with traits, confusion of the terms "adaptation" and "fitness." It then explains how activities in the unit are intended to help students overcome these problems.

A diagnostic test, which could be used as a pretest, posttest, or both, is designed to reveal important student misconceptions and provides notes for the instructor to interpret student responses. A set of student handouts and masters for overhead transparencies includes notes for the instructor about conceptual problems each was designed to address. The laboratory activity on the evolution of bead bugs is followed by problem sets on variation and adaptive traits designed to address specific student misconceptions.

The first three parts can be used independently or in combination with the laboratory activities and problem sets after students have learned the relevant concepts. The materials help instructors accomplish three tasks essential to overcoming critical barriers to student learning: diagnosing student deficiencies, creating dissatisfaction with misconceptions, and providing opportunity for application and practice.

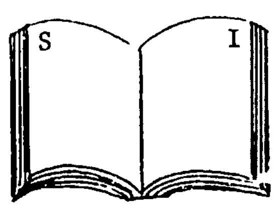
About the Authors

Charles W. Anderson, coauthor of the module, is director of the project Overcoming Critical Barriers to Learning in Nonmajors' Science Courses. He is a senior researcher at the Institute for Research on Teaching and an assistant professor in the Department of Teacher Education, Michigan State University. Beth A. Bishop is a graduate student in the Department of Entomology, Michigan State University.

6

Table of Contents

Organization of Pages in this Module



Student Pages

Instructor Pages

Pages with instructional materials to be used by students are on the left side.

Pages with information for instructors are on the right side.

Preface

We hope that using this module helps you gain insight into your students' understanding, and misunderstanding, of evolution by natural selection. One of its main purposes is to provide opportunities for you to learn about your students' thinking. Because of what you discover about their thinking, you may have to move more slowly and cover less content than you would like. That may seem like a problem, but we don't think so. It is far better to have students learn to understand a little science than to have them misunderstand a lot.

ERIC Full Text Provided by ERIC

I. Introduction

Memorizing or Making Sense?

If any of your former biology students were asked to explain the theory of evolution by natural selection, as they understood it, what would you want their explanation to be? Which concepts do you feel are crucial to understanding this theory and to making sense of more sophisticated modern evolutionary theory? What kind of understanding of the mechanism of evolution do you want your students to possess when they are making decisions about such questions as "equal time" for creationism?

Will your goal be met if students simply memorize enough facts to pass tests (while, perhaps, retaining the erroneous idea that the human tailbone degenerated through disuse)?

We believe that it will not.

Even a minimal understanding of this topic goes well beyond the skills required to anticipate correct answers on multiple-choice tests. We will begin this module by describing what we consider a minimal understanding of evolution by natural selection to be.

The importance of understanding natural selection. When Charles Darwin and Alfred R. Wallace proposed the theory of evolution by means of natural selection in the mid-1800s, they catalyzed a revolution in the science of biology. Not only did their theory provide a plausible explanation for the long sought-after mechanism of evolution, it also provided biology with a unifying philosophy.

Today, the concepts of both evolution and its primary mechanism, natural selection are accepted as fact by virtually all biologists. Evolution by means of natural selection provides the conceptual framework upon which much of modern biological theory is based.

Therefore, this theory has a primary place in biology curricula. Understanding of many modern ideas (for example, theories of speciation, the phylogenetic system of classification, gene flow, genetic drift, etc.) depends on a basic understanding of evolution by natural selection.

Conceptual goals of the module. What does this basic understanding consist of, and when can a biology instructor be satisfied that students have obtained it? These questions are faced by all instructors of beginning and nonmajors biology classes. There is much these students do not know and teaching them is often a challenge. In this module, we focus on one part of that challenge: helping students to understand how populations change over time.

We feel that minimal basic understanding of evolution is attained when students can explain (in general with respect to specific examples) how the separate processes of random mutation and natural selection work in concert to change the nature of populations over time.

We have chosen to emphasize the above concept for several reasons. First, we believe this concept is absolutely essential in order for students to make sense of evolution. Second, this concept is difficult for students to understand. Simply explaining it to students is not enough no matter how skillful the explanation is. Third, most textbooks and courses fail to treat this concept adequately, forcing students to grapple with more advanced and difficult treatments before they have mastered this fundamental idea.

Critical Barriers to Understanding Natural Selection

The concept of evolution by natural selection as presented in the previous section appears easy to understand. Actually the concept and the ideas embodied within *are* fairly simple, but *only after one understands and accepts them*. Such understanding and acceptance may not be easily gained by beginning biology students. The students in our college nonmajors biology course have taken and passed an average of 1.5 years of previous high school and college biology courses. Yet their answers to test questions reveal a surprising lack of understanding. Consider the following examples:

> "When the salamanders started living in caves, their eyesight was no longer important. The new generations of salamanders, through natural selection, were born with nonfunctional eyes."

> "The theory of natural selection states that if an organism requires a special adaptation, over the years they will slowly acquire it."

The above statements were taken from student responses to questions on tests taken *after* these students had received instruction in natural selection. We know that these students had both listened to and read clear explanations of the process of evolution through natural selection, yet they still gave responses like those above.

Why do these ideas pose such a problem for students? How can they complete instruction in evolution and still misunderstand? This module is based on one kind of answer to these questions. The answer arises from extensive research comparing inexperienced students with scientific experts as both deal with scientific problems. In general, this research shows that the students think and act in ways that make sense to them, but that are incompatible with scientific thought.

The presence of these alternate ways of thinking makes the learning of science a far more complicated process that scientists normally imagine. Students cannot simply absorb or memorize scientific content. They must reassess and restructure their intuitive knowledge of the world. Furthermore, they must abandon misconceptions or habits of thought that have served them well all their lives in favor of new and unfamiliar ideas.

The old habits of thought can be amazingly resistant to change through instruction. They persist even after students have apparently learned the scientific alternatives. Many students become quite good at learning what is expected of them to pass science tests while continuing to use their old ideas in "real world" situations. We have adopted a phrase from David Hawkins and describe these enduring habits of thought that interfere with scientific thinking as "critical barriers" to the learning of science. Hawkins defines these as "irretrievably elementary stumbling blocks" that prevent students from fully understanding scientific concepts and principles. This module is the product of a research and development project in which we have tried to understand the critical barriers to student learning in a nonmajors' biology course, then design materials and activities that will help students overcome those barriers.

There seem to be several critical barriers that prevent many of our students from attaining a scientific understanding of the process of evolution by natural selection. In general students enter our course believing that they already understand the process fairly well. Unfortunately, they are usually wrong. Figure 1: A & B, on the next page, contrasts the process as it is typically understood by our students with the process as scientists understand it. These conceptions of evolution by natural selection are different in many respects, the most important of which are the following three issues:

1. Students fail to make a distinction between the separate processes responsible for (a) the appearance of traits in a population and (b) the survival of such traits in the population over time.
2. Students fail to recognize that the process of natural selection is dependent on differences (in genetic traits and in breeding success) among individual members of a population.
3. Students misinterpret the nature of evolutionary change in populations, believing that *all* individuals change slowly over time.

The following sections contain a detailed discussion of the misconceptions held by students with respect to each issue. Although, in reality, correct scientific understanding of evolution by means of natural selection is achieved only by integrating the separate issues into a coherent whole, they are discussed separately below for ease of organization. Examples in each section are taken from responses to pretest and posttest questions our students gave and are included bec[illegible] they are representative of misconceptions students hold with respect to [illegible] issue discussed.

Origin and survival of new traits in populations. Biologists recognize that two distinct processes, fundamentally different in cause and effect, affect traits exhibited by populations. New traits originate by random changes in genetic material (mutation, sexual recombination), and then survive or disappear due to selection by environmental factors (thus affecting the composition of the population as a whole).

In contrast, students possessing naive conceptions do not recognize the existence of two processes affecting the population. The sole process seen to affect traits (often called by students "natural selection" or "adaptation") is viewed as affecting only the quality and/or appearance of traits.

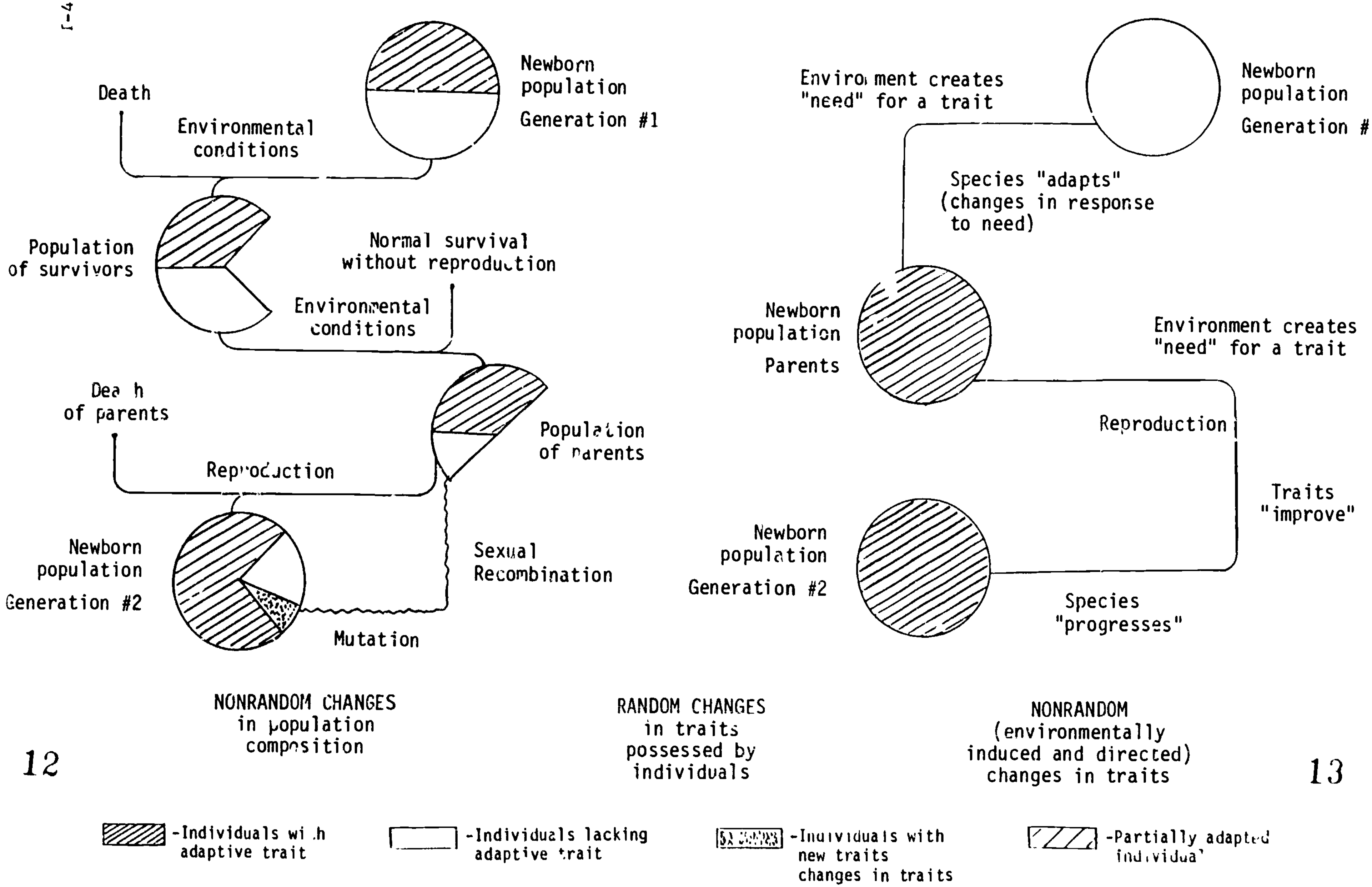
Furthermore, many students believe that environmental conditions are directly responsible for changes in traits.

Example: "Because with each generation the cheeta became more developed. The body began adjusting to the environment in order to survive."

I-4

A. Conception of Evolution by Means of Natural Selection

B. A Generalization of Students' Naive Conceptions



There is much variation in this particular naive conception concerning the details of students' belief. As far as when (in the reproductive cycle) the environment exerts its effect, two beliefs are common. Students may believe that the environment acts directly on living organisms, which alter their traits in response to environmental conditions and subsequently pass on all or part of these alterations to offspring. Alternately, students may believe that the environment (somehow) affects the genes as they are passed to offspring. Inherent in this later belief is a conception of "progressive evolution," whereby the genes of each successive generation "improve" or "fit" more closely to the environment.

With regard to the *mechanism* of environmentally induced change in traits, students' beliefs are various and often unclear. The most often stated effect of the environment on traits is creating *need* or *purpose*.

Examples: "Eventually the animal [cave salamanders] didn't need the sight and through the genes it was eliminated."

"Modifications for another essential need [then] evolved."

Some students are satisfied with this explanation as is: that *need* determines the appearance and modification of traits without explaining how it does so. Others incorporate, into their conception, an explanation of how need affects traits. The two most commonly used explanations are "use-disuse" and "adaptation."

The use-disuse explanation is classic Larmarckianism. Use (or disuse) of body parts results in development or deterioration of those parts. While this point is fairly easy to disprove to students in the short run (i.e., building muscles will not result in stronger children), it is difficult to convince them that long-term use or disuse will have no effect. They may believe that long-term use or disuse of body parts (for example, the cultural practice of binding the feet of young females in Oriental countries) will ultimately result in genetic modification of that body part (i.e., females born with smaller feet). But the influence is only believed to work over long time periods (i.e., hundreds or thousands of years) instead of at each generation.

Examples: "Eventually over the years they [cave salamanders] became blind because of not using their eyes."

"Therefore, they were meant to see, but since they no longer used a limb of their body, it lost its function."

With students who use the "adaptation" explanation of environmental effects, naive beliefs are often difficult to detect. These students are using a legitimate evolutionary term, but it is clear from their statements that they are *not* using the evolutionary definition of the word. Instead, they are using the word in reference to an individual (and/or collective) response to a "need."

Examples: "Their legs could have adapted by growing longer."

"Adaptation--for survival purposes the anatomy changed to enable cheetahs to catch their prey."

This issue as a whole is perhaps the most difficult one for our students. The idea that the environment directs the appearance and development of traits is very logical and appealing. To achieve proper understanding students must accept not only the idea that random processes cause the appearance and modification of a given trait, but also that the environment in no way influences this. In order for students to understand evolution they must accept that the environment affects *only* the survival and spread of traits, *after* their appearance in the population.

The role of variation within populations. Biologists understand that variation within populations is a prerequisite for evolutionary change. Differences among individuals with respect to genetic traits result in differences in reproductive success due to selection pressures imposed by the environment. This within-population variability is clearly depicted in Figure 1-A.

Students possessing naive conceptions often do not consider this variability as relevant, viewing selection as a process occurring to the species (or population) as a whole (see Figure 1-B).

Examples: "They [cheetahs] might have had to run fast to escape predators and gradually their muscles and bones changed to adapt to this."

"The cat [cheetah] was in an area where the environment changed and he had to adapt by learning to increase his speed."

While these students may understand that organisms differ from one another, they view this difference as irrelevant to evolution.

As in the previous issue, correct scientific understanding is achieved not only by recognition of the importance of variability to differential reproduction (rather easily achieved), but also by *rejection* of the naive conception, that selection involves a collective response on the part of the species or population.

Evolution as changing proportions of individuals with discrete traits. Biologists recognize that changes in traits appear sporadically and at random. Gradual progression in evolutionary change has to do with the spread of given traits through the population over the course of many successive generations. This is depicted in Figure 1-A by the increase in the percent of shading (proportion of individuals possessing adaptive traits) in the population circle.

In contrast, many students view evolution as consisting of the gradual, progressive, "improvement" or deterioration of traits over the course of successive generations. This is depicted in Figure 1-B by an increase in the degree of shading in the circle as a whole.

Example: "As sight was not needed, these salamanders in the cave passed down genes with less ability to see until they had evolved to the blind ones."

Again, correct student understanding of this issue involves not only acceptance of the scientific conception, but also rejection of the naive notion of gradual improvement in traits. If this rejection does not occur, students may believe that evolution involves not only the spread of traits through populations, but also an improvement of trait quality as it is passed from one generation to the next.

Terms that are confusing to students. Another stumbling block to correct learning of the theory of natural selection is the confusion in terms used in connection with it. Two such terms--"fitness" and "adapt"--can cause extreme difficulty, since their meaning, in everyday language, is very different from their usage in evolutionary terms.

1. Adapt/Adaptation. When one hears, in everyday conversation, that an individual adapts, one understands that individuals respond to environmental conditions by altering their form, function, and/or behavior. When one hears, in evolutionary terminology, that organisms adapt, one understands that the composition of the population changes over a period of several generations. These two definitions are quite different, and students, hearing this word used, often construct meanings in terms of the former familiar definition.

   Using the everyday definition for the process of adaptation in the evolutionary sense also tends to be reinforced by the misconception explained in the previous section, that is, that environmental conditions influence appearance and modification of traits.

2. Fitness. Biologists use the term "fitness" to express the capability of individuals (or genes) to produce surviving offspring. But, in the everyday sense, this word means, "big, strong and healthy." This discrepency in definitions can confuse students. The confusion may be amplified by inaccurate popularizations of evolution which state, "Only the strong survive."

Summary. The major contrasts between the scientific conception of the process of evolution through natural selection and our students' conceptions are summarized in Table 1. The naive conceptions described in Figure 1-B and in Table 1 are the critical barriers to understanding that this module is designed to overcome.

ERIC

Table 1

Contrasts between Scientific Conception and Naive Conceptions of Natural Selection

Issue	Scientific Conception	Naive Conceptions
Major Issues		
Origin and survival of new traits in populations	Two separate processes: 1. Random genetic events affect the appearance and quality of the trait itself. 2. Environmental conditions affect only the survival and spread of existing traits.	Only one process is recognized. Environmental conditions are seen to affect the development of traits over time by causing: 1. Need or purpose 2. Adaptation 3. Use/disuse Environmental effects are understood to influence individuals and/or genes. No distinction is made between appearance of a trait and its survival in the population.
The role of variation within populations	Individual differences recognized as essential. 1. Differences in traits 2. Differences in breeding success related to environmental conditions	Individual differences are not seen as relevant. The species (as a collective) is seen to change over time.
Evolution as changing proportions of individuals with discrete traits	Evolution consists of a change in the *proportion* of individuals in a population exhibiting a given trait over several generations.	Evolution seen as consisting of a change in the *quality* of traits possessed by individuals over several generations.
Confusing Terminology		
1. Adaptation	Passive process in which the composition of traits exhibited by a population changes over several generations.	Active process in which individual organisms respond to environmental conditions by altering their form, function, or behavior.
2. Fitness	Ability of organism to produce offspring which survive to maturity.	Possession by an organism of "desirable" characteristics such as size, strength and intelligence.

ERIC

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 cours 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.

ERIC

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?

ERIC

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 unde.stand.

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."

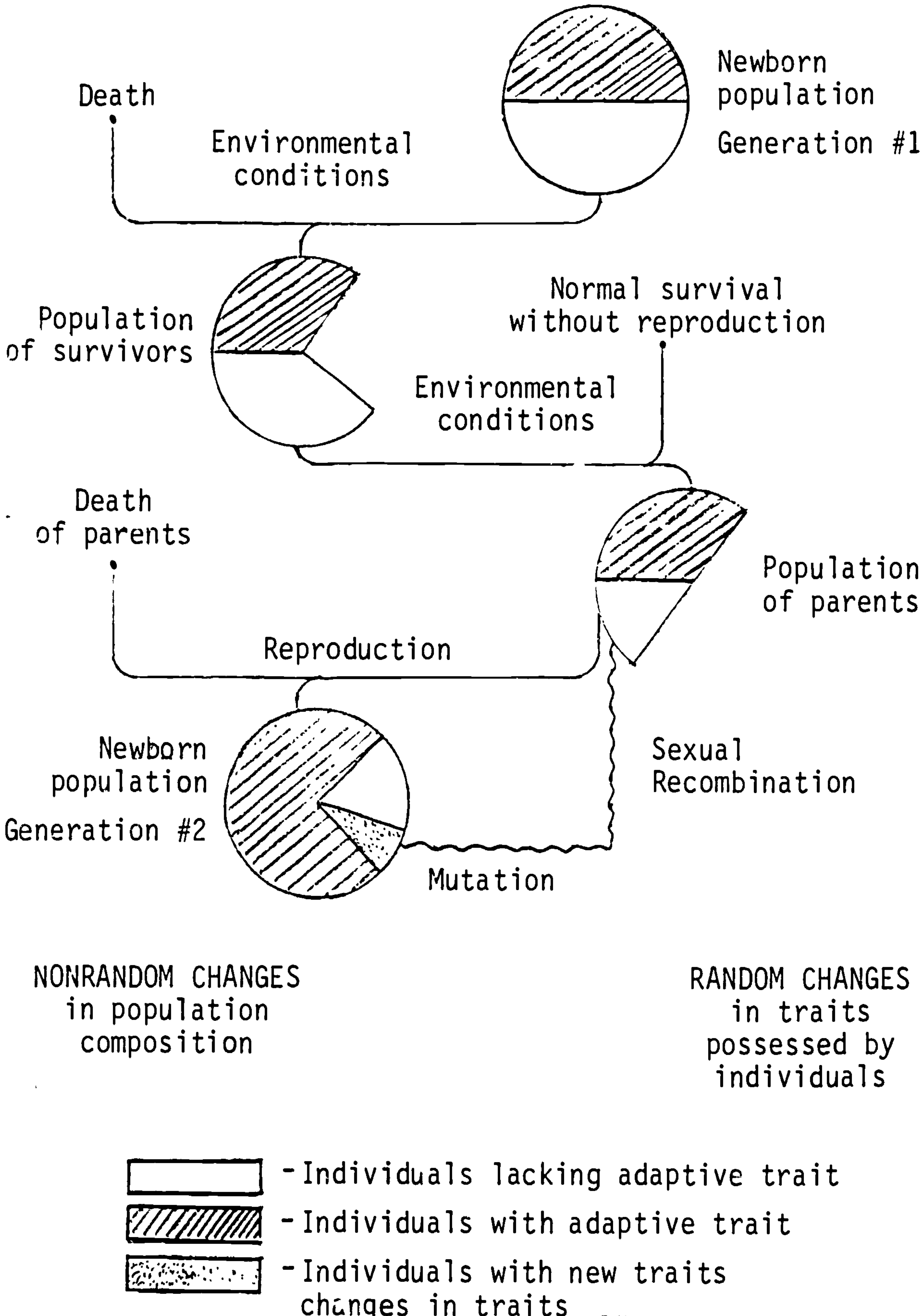
Ideal answers should explain that Sandy was fittest because he left the greatest number of surviving offspring.

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.

ERIC

EVOLUTION BY NATURAL SELECTION



III. Materials for Lecture or Discussion

This section contains a series of copy-ready masters for use as overhead transparencies and student handouts.

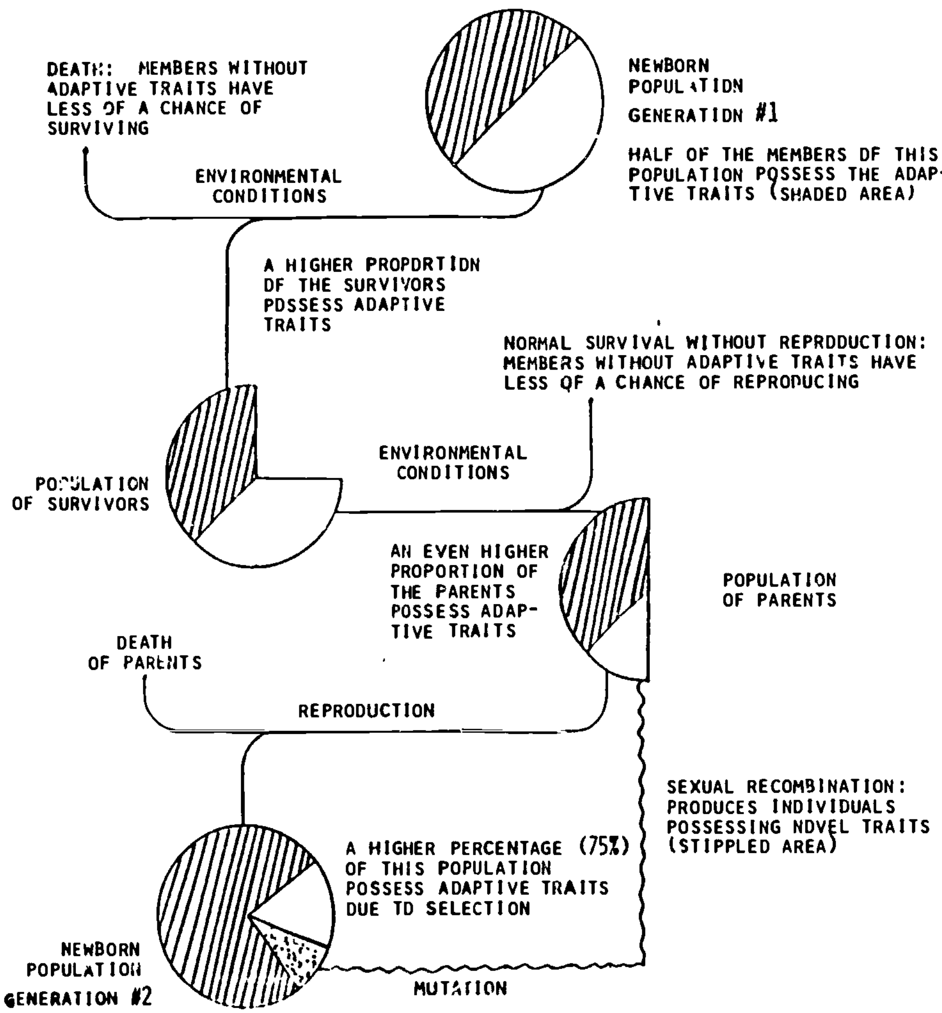
1. The overhead transparencies may be used as traditional lecture supplements, or as a basis for discussion in lecture and/or recitation sessions.

2. The student handouts may be discussed in lecture and/or recitation or used by students as study guides.

Each sheet is designed to address one or several key concepts and/or to confront important critical barriers. They are found in copy-ready form on the left-hand pages, with commentary, explaining the purpose of the sheet, on the page on the right.

Contents

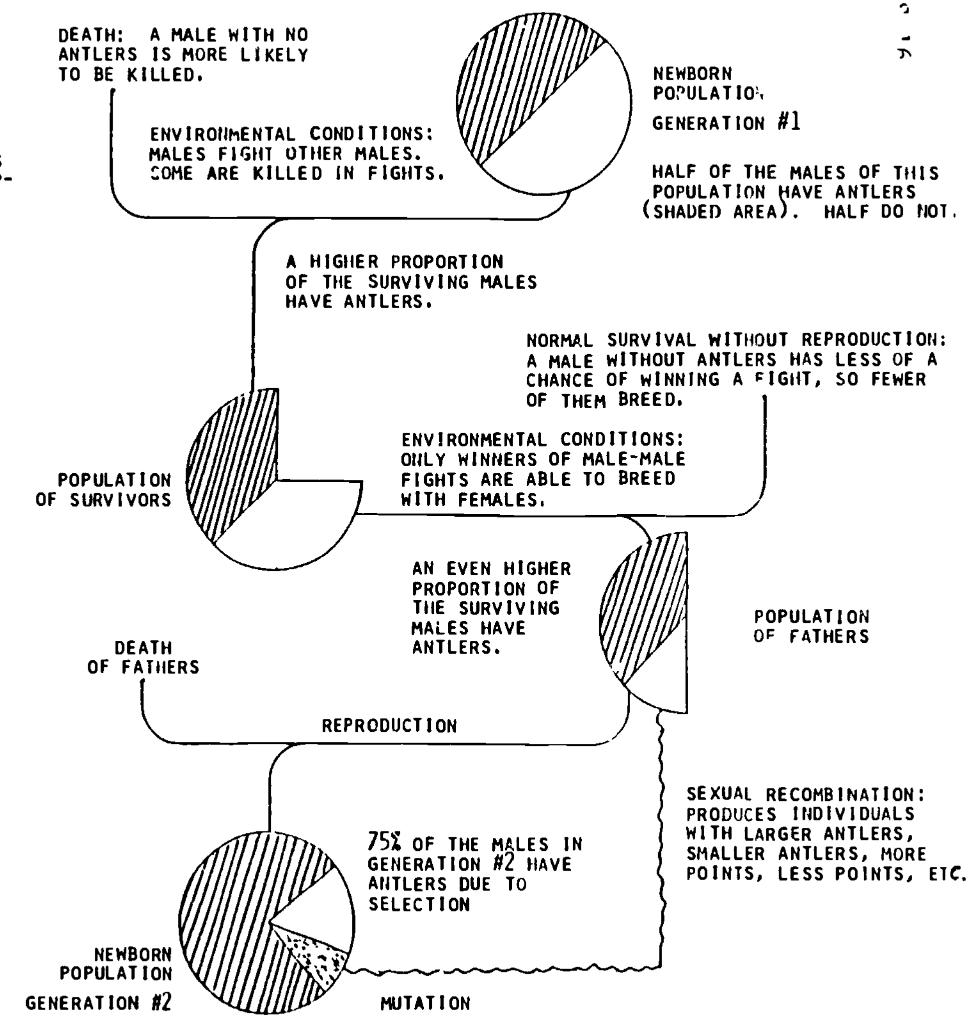
EVOLUTION BY NATURAL SELECTION



Nonrandom changes in population composition

Random changes in traits possessed by individuals

HOW COULD DEER HAVE EVOLVED ANTLERS?



Environment "selects" for male deer with antlers

Random mutation and sexual recombination produce changes in antlers

[ ] - Individuals lacking adaptive trait
[hatched] - Individuals with adaptive trait
[stippled] - Individuals with new traits changes in traits

BEST COPY AVAILABLE

Evolution by Means of Natural Selection

This overhead transparency is identical to the figure depicting the scientific conception as explained in the introduction (Figure 1A). All major issues are included in this diagram as well as the way in which the issues are connected.

Below is a summary of the way in which the diagram presents scientific conceptions of the three major issues to students.

1. Origin and survival of new traits in populations. The two processes responsible for the change in traits in a population are represented on different sides of the diagram, nonrandom, environment-dependent selection (illustrated on the left) is shown to affect only the composition of the population, while random, genetic changes are depicted as affecting *only* the appearance and modification of traits in individuals. It is recommended that instructors point out that novel traits may be favorable, unfavorable, or neutral.

2. The role of variation within populations. The figure illustrates the importance of individual variation in traits to the process of natural selection. Initially the population is depicted as variable (some members possessing adaptive traits, others not possessing them). Selection is shown to act by removing differential proportions of the two groups.

   In addition, the figure illustrates that the direct cause of selection is environmental conditions. It is recommended that instructors point out that this is the *only* point where the environment influences population traits.

3. Evolution as changing proportions of individuals with discrete traits. The figure shows an increase in the proportion of individuals possessing adaptive traits over the course of two generations (depicted by an increase in the shaded area from 50% to 75%). It is recommended that instructors point out to students that this constitutes evolutionary change. Additionally, it is suggested that instructors point out that the *quality* of the adaptive trait(s) has *not* changed from one generation to the next.

This overhead transparency is useful in aiding the initial presentation of the general ideas of evolution by means of natural selection. It also may be used in student "practice sessions" by posing evolutionary questions and helping students apply the principles of the figure to specific examples (how could X-organism have evolved Y-trait?). We have found, with our students, that such practice is extremely valuable to the learning process.

We have also found that using nontypical, nonanimal examples in these practice sessions helps students to understand how the principles of natural selection can be used to explain the majority of features possessed by organisms today. Suggested examples to use include:

How could cacti have evolved spines?
How could positive phototaxis have evolved in euglena?
How could migration have evolved in birds (bats, butterflies)?
How could fall loss of leaves have evolved in deciduous trees?
ETC.

Commentary

This student handout supplements the previous overhead transparency (page 15). The first half of this handout is virtually identical to the overhead transparency except that more detailed explanations are provided. The second half presents to students the principles of evolution by natural selection as applied to a specific example (evolution of antlers in deer). The handouts are designed to clarify the scientific conception of the three key issues:

1. Origin and survival of new traits in populations. Comments explain the role of the selection process as differential survival/reproduction, and the role of mutation and sexual recombination as changes in traits themselves.

2. The role of variation within populations. Comments explain variability in populations and the role the environment plays in differential survival and differential reproduction.

3. Evolution as changing proportions of individuals with discrete traits. Comments explain that evolution consists of an increase in the proportion of individuals possessing adaptive traits in the successive generations.

It is suggested that instructors encourage students to use this handout as a *guide* to understanding the principles of evolution by natural selection and in applying these principles to practice problems. This sheet is also helpful to students attempting to understand why their answers on tests were marked incorrect.

ERIC

How Do Populations Change Over Time?

1. What causes a new trait to appear?

All new traits and any changes in existing traits can occur in individual members of a population *only* as a result of the random processes of sexual recombination and/or mutation.

a. Mutations are "mistakes" in the genes. When mutations occur in gametes (eggs & sperm) the resultant offspring may exhibit a trait which is different from either parent. Example: A mutation in a gene that dictates the thickness of an insect's external skeleton occurs in an insect sperm. The offspring have thicker external skeletons than their parents. As a result, insecticides are not able to enter the insect body and the offspring are resistant to insecticides.

b. Sexual recombination. In sexually reproducing organisms, part of the the mother's genes combine with part of the father's genes. As a result of this mixing, offspring may possess traits which are different from either of their parents.

Comments

Note that *only* random (nondirected) processes produce new traits or a change in existing traits. The following environmentally directed influences do *not* cause a change in genetic traits.

a. Need--When an organism needs to have a trait which it does not have, it dies. Millions of species have become extinct because they did not have traits they needed in order to survive. (example: Dodo birds became extinct because they could not fly, which they needed to do in order to escape predators.)

b. Using or not using body parts. Although an individual may develop body parts by using them (example: a weight lifter), the genes which they pass to their offspring are not affected (for example, a man's children will be the same whether or not he lifts weights).

As another example, humans have been cutting the tails of some breeds of dogs for hundreds of years, yet the puppies continue to be born with tails.

c. Responding to the Environment--Adapting. When an individual adapts to a situation, it does not affect the genes he or she passes to offspring. Therefore the traits are unaffected.

2. What does natural selection do?

All populations contain members that do not reproduce, either because they die before maturity or they do not obtain mates. *Natural selection* refers to the fact that this process is not random but rather a "selection" of certain individuals by the environment. The individuals that succeed in reproducing

Commentary

This student handout addresses the three key issues of evolution by means of natural selection. The issues are raised by posing questions for students to respond to. Directly under each question is an answer explaining the scientific conception of the issue and comments designed to expose the errors of the naive conception.

1. What causes a new trait to appear?

   The answer to this question explains that new traits and changes in existing traits are due only to random change in genetic material. In addition the answer provides a brief explanation of the *nature* of the processes of mutation and sexual recombination and *why* they can cause a change in traits.

   The comments to this question provide an explanation of why the environmentally imposed influences that many students believe cause change (i.e., need, adaptation, use-disuse) *cannot* affect genetically determined traits.

2. What does natural selection do?

   The answer to this question explains the concepts of natural selection, that the process is *not* random and that it is the result of environmental conditions.

   The comments to this question explain that natural selection *only* affects existing traits and does not influence the appearance of traits. This is an extremely important point since students possessing naive conceptions often view selection as affecting the appearance of traits.

do so because they possess traits that are adaptive in the environment. Other 'uals that possess other nonadaptive traits die without reproduci Thus, natural selection means that adaptive traits (those which increase an individual's chances of surviving and reproducing) appearing in individual organisms are retained in the population, are passed on to offspring, and, over the course of many generations become established in the population as a whole. Other nonadaptive traits are eliminated and do not become established.

Comments

Note that natural selection works because individuals in a single population are different from one another. Random mutation and sexual recombination produce new traits in individuals. Natural selection *only* causes the retention of the adaptive traits and elimination of nonadaptive traits from the population. This is the reason why it does not matter that most mutations are harmful, since *selection* causes individuals possessing harmful mutations to die before passing on their "bad genes."

3. What kind of changes occur in an evolving population?

The only way evolutionary change in a population can be detected is by comparing one generation with previous generations. When one does this, one finds that more individuals in the new generation possess adaptive traits. For example, assume that 80% of the individuals in a certain caterpillar population possess spines. These spines are adaptive because they prevent the caterpillars from being eaten by birds. A caterpillar with spines has a greater chance of growing up to be a butterfly than a caterpillar without spines.

We know this caterpillar population has been recently evolving spines because two generations ago only 60% of the individuals possessed spines and ten generations ago only 25% of the individuals possessed spines.

In a nutshell, evolutionary change refers to a change in the composition of a population over time, and occurs because:

1. Occasionally an adaptive trait (spines) occurs in one member of the population as a result of mutation and/or sexual recombination.

2. This adaptive trait gradually becomes established in the population over many generations (e.g., increase in the percent of spiny caterpillars) because the descendents of the original mutant are more successful at reproduction than other members of the populations (e.g., natural selection).

Comments

Note that the *quality* of adaptive traits does not change from one generation to the next. The caterpillars in our example are not any spinier than their parents were. They are also not any spininess than their ancestors were ten generations ago. Each additional increase in spininess *must* be due to an additional chance mutation.

3. What kind of changes occur in an evolving population?

This question explains that gradual, progressive evolutionary change consists of changing frequencies of traits from one generation to the next. The concept is explained with reference to a particular example (spiny caterpillars) to aid student understanding.

The comments to this question explain that changes in the traits themselves are due to random processes and therefore are *not* progressive and gradual. This explanation is designed to illustrate to students why the naive conception of a gradual improvement in the quality, is incorrect.

Evolutionary Terminology

1. What does the term "fitness" mean?

The term "fitness" refers to an organism's ability to produce surviving offspring. The more offspring that an organism produces, that, in turn, survive to produce offspring themselves, the more of that organisms traits will be passed to each succeeding generation. For example, if brown-eyed humans produced 5 children for each 1 child produced by a blue-eyed human, we would say that brown-eyed people were more "fit."

Commentary

Note the tern "fitness" does not refer to size, strength, intelligence or health. A bigger or stronger organism does not always produce more offspring. Fitness refers only to the ability to produce surviving offspring.

2. What does adaptation mean?

The process of adaptation refers to the composition of a population of organisms changing over time. The term is synonymous with "evolution by natural selection." Each generation consists of higher percentages of individuals possessing adaptive traits.

Note that this term does *not* have the same meaning as the word "adapt" in the everyday sense. When one says that someone adapts, one means that the individual changes. The term "adaptation" does not refer to individuals changing, only to changes in the population as a whole.

3. What is an "adaptive trait?"

Biologist call any trait "adaptive" if it increases an organism's chance of producing offspring (e.g., increases fitness). For example, the trait of white-colored coats is adaptive for polar bears because it increases the animal's chance of catching prey, surviving, and therefore producing offspring.

For the most part adaptive traits do not result from changes in individuals. Polar bears are born adapted to their environment; they do not develop adaptive traits in response to their environment.

Commentary

In this student handout, students' naive conceptions concerning evolutionary terminology are directly confronted. As explained in the introduction, naive conceptions with respect to these issues are most likely a result of everyday meanings being applied to evolutionary terms.

To aid in clearing this confusion, students are directly asked to provide functional definitions of the term. Immediately following the question is the correct response. The commentary section clearly explains the differences in meaning between "scientific" and "naive" definitions.

Evolution of Pesticides Resistance in Insects

Natural Selection

Generation #1

Insecticide - death of susceptible individuals

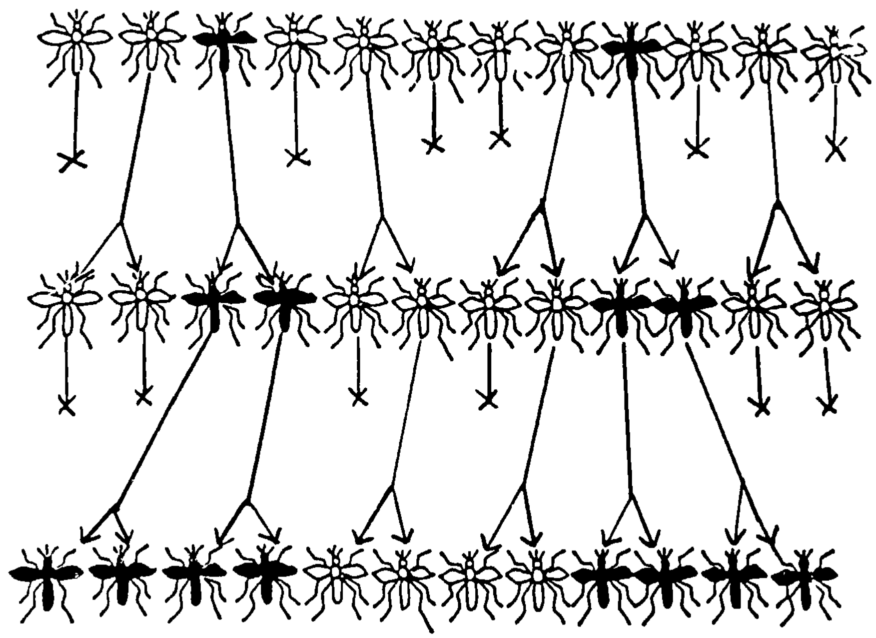
reproduction

Generation #2

Insecticide - death o susceptible individuals

reproduction

Generation #3



Inheritance of Acquired Traits

Generation #1

Insecticide & Reproduction

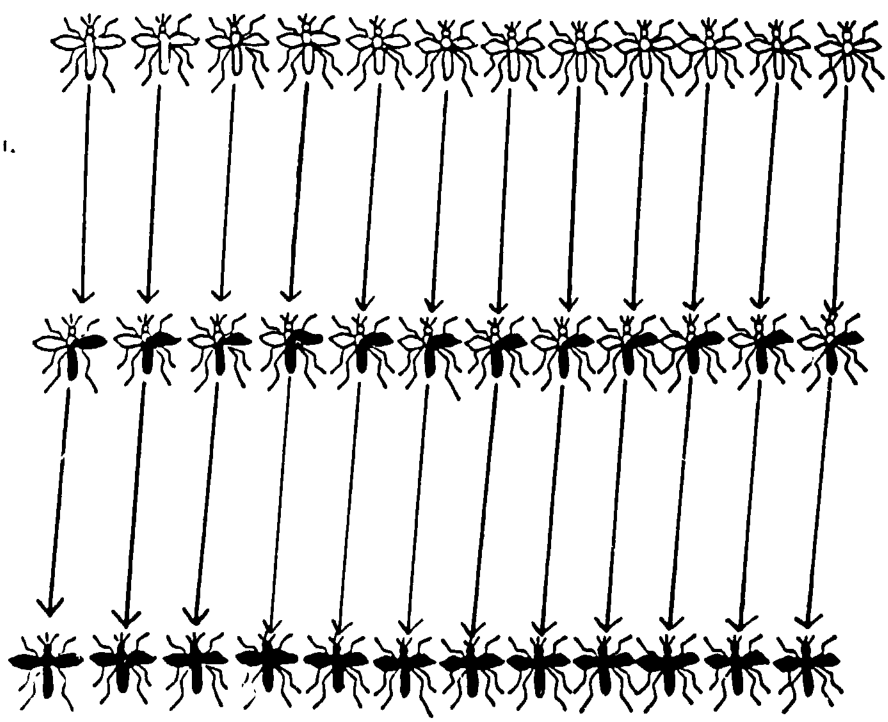
Immunity built up & passed to offspring

Generation #2

Immunity built up in parents & passed to offspring

Insecticide & Reproduction

Generation #3



Commentary

In this lecture overhead, the scientific conception of evolution by natural selection is directly contrasted with the student naive conception. The contrast is done by applying the ideas of each conception to a familiar example: Evolution of resistance in insects.

The overhead illustrates the difference between the two conceptions with respect to two of the three key issues ("the role of variation" and "the process of evolution"). Although this sheet does not present fully the issue of "the origin of new traits" directly, students are able to see the *lack* of the naive conception with respect to this issue in the scientific explanation at the top of the sheet (i.e., insecticide does not affect the *appearance* of the trait of resistance).

The value of presenting both explanations to students simultaneously is twofold. First, students' naive conceptions often lack details. Exposing the implications of their belief to them (i.e., acquired traits being passed to offspring) often aids in rejection of that belief.

Second, because of the relative complexity of the scientific conceptions, students may not understand how these processes produce evolutionary change. This overhead illustrates that the two explanations result in identical results (i.e., a population of insects resistant to insecticides), thus making the acceptance of the scientific conception easier for students.

We suggest that instructors "work" through each explanation and point out to students exactly where the naive conception falls short of reality (i.e., the acquiring of resistance and passing this acquired trait to offspring). Instructors may also need to point out the difference between acquired "immunity" and evolved "resistance" since these terms are often used interchangeably by students.

IV. Laboratory Activities

This section contains a suggested laboratory activity. As in previous sections, pages on the left are student handouts; right-hand pages contain information for instructors.

We believe that it is especially important for students to think about and answer the questions at the end of each handout. These questions require them to use their knowledge of evolution by natural selection to explain what they have observed. Many students will benefit from postlab discussions of these questions.

This lesson should take one or two hours in all, depending on the length of discussion and the speed at which your students work.

ERIC
Full Text Provided by ERIC

LABORATORY WORKSHEET

Evolution of "Bead Bugs"

Materials

Multicolored flowered cloth material
Beads: four different c .ors (for example, blue, pink, yellow, and gray)
Overhead transparencies for class data

Introduction

You should work in teams of four to five students.

During this laboratory exercise you will observe the evolution of a hypothetical population of "bead bugs." It is necessary for you to simulate the process of evolution by means of natural selection rather than observe it directly because of the time involved (from a few years to millions of years, depending on the organism) for the event to occur naturally.

You have available to you, a species of insect, "bead bugs" (represented by beads) and the environment in which the bug lives (represented by flowered cloth). The following are some relevant facts about "bead bug" biology.

Bead bugs live in flowered meadows and feed on pollen. The only death in a population is due to predation by birds. Each year, birds eat about one half the total population of bugs in a meadow.

Bead bugs reproduce just once a year in June. Reproduction is asexual. Each parent produces one offspring.

You will simulate four generations of bead bugs by repeating 4 times this cycle of predation and reproduction.

Setting Up

1. Variation among individuals is a characteristic of organisms of the same species. Observe the bead bugs in your jar.

   What are some of the differences between individual bead bugs?

2. You will be working with a population of bead bugs which lives in a meadow. You will start with 40 bead bugs. Count out 20 blue beads and 20 pink beads and scatter them randomly on the meadow.

   What is the biological definition of a population?

Commentary: Evolution of "Bead Bugs"

Materials

Multicolored flowered cloth
Beads: four different colors (for example, blue, pink, yellow, and gray)
Overhead transparencies for class data: Data Tables 2 and 3

Advance Preparation

Provide each group of students (4-5 students per group) with one square of the cloth material. Each square of material should be approximately 16" x 16".

Provide each student with a jar or beaker containing the four colors of beads. (Students should be provided with at least 40 beads of each color.) Make overhead transparencies of Data Tables 2 and 3 (page S-28).

The success of this activity depends on the color of the beads and the cloth. Beads should be small enough so they are not easily spotted. One of the original colors (blue in this case) and one mutation (gray in this case) should closely match one of the major colors in the cloth (i.e., be hard to see). The other two colors of beads should be more easily seen against the cloth background.

Rationale

Students will observe that the color composition of the bead bug population changes over time.

Students should be able to recognize the mechanism of color change as differing survival rates and reproductive rates of different colored beads.

Students will observe that mutation causes new colors to appear in the population. Students should be able to recognize that he nature of the environment does not influence the number and/or kind of mutations which occur and that the success of any mutation is dependent on particular environmental conditions.

Suggested Use

It is suggested that instuctors take the class as a whole through the first generation in order to make sure students understand the instructions.

It is recommended that instructors hold a postlab discussion in which class data are accumulated on the overhead transparency (the master is at the end of this section) and the questions at the end of the laboratory handouts are discussed.

3. You are now ready to simulate predation on the first generation.

You will act as the bird predators. Think about how birds capture bugs: They fly over an area, spotting and capturing bugs, one at a time. Choose one or two students in your group to act as birds. These students should pick up and remove 20 beads from the meadow, picking the beads that are easiest to see and catch.

4. Count the number of bead bugs of each color that remain in the meadow. Record this number in Data Table 1 (page S-25) under the column "First Generation After Predation." These are the bead bugs which will produce the second generation.

a. What percent of blue bead bugs survived to reproduce? (Divide the number of blue bead bugs left after predation by 20.)

b. What percent of pink bead bugs survived to reproduce? (Divide the number of pink bead bugs left after predation by 20.)

c. How do your percentages compare with the class average?

Reproduction

It is now June and time for your bead bugs to reproduce. As explained earlier, reproduction in bead bugs is asexual. Each parent gives birth to one offspring. Offspring are the same color as their parent except if a mutation occurs.

To simulate reproduction:

1. Look at the number of each color remaining after predation in the meadow.

2. Add an equal number of beads for each color (for example, if 7 blue beads are left, add 7 more).

3. You should now have 40 beads in the meadow.

Mutation

Color mutations occasionally occur in bead bugs. Two common color mutations result in blue beads producing yellow offspring and pink beads producing gray offspring. On the average, each mutation occurs once a generation. To simulate this, remove one blue offspring and replace it with one yellow offspring. Remove one pink offspring and replace with one gray offspring.

You are now at the beginning of the second generation. Determine the number of beads of each color in the meadow and record these numbers in the appropriate columns in Data Table 1 under "Second Generation Before Predation."

ERIC

Answers to Questions

1. Students probably will recognize first the obvious difference of color. With encouragement, students may recognize more subtle differences between individuals, such as differences in size, shape, and weight.

2. It is important that students understand that a population consists of organisms of the *same species* in a given area, also that evolution concerns populations.

4. At this point we suggest that laboratory instructors collect individual data and summarize it on an overhead transparency of Data Table 2 (page S-28).

From this table students should recognize:

1. Not all colors of bead bugs survived at the same rate.

2. The environment determined which colors survived at the highest frequencies.

3. The colors will not be equally represented in the next generation.

It is recommended that students be introduced to the following terms:

Differential Survival: Different colors of beads have different survival rates. This leads to differential reproduction. Different colors as a whole produce different numbers of offspring.

It is recommended that after students finish the exercise, instructors compile class results of the number of bead bugs of each color in the fifth generation and present them on an overhead transparency of Data Table 3 (page S-28). This process is a safeguard against individual groups obtaining atypical results.

It is also recommended that students answer questions with reference to whole-class data.

Repeat 3 more cycles of predation and reproduction, and mutation, filling in your data tables as you go. To help you, a summary of steps follows.

Summary

1. Scatter 20 blue beads and 20 yellow beads on meadow.
2. Acting as bird predators, remove 20 beads from the meadow.
3. Count the number of each color of beads left in the meadow. Record this number in Data Table.
4. Simulate reproduction.
5. Simulate mutation.
6. Record the number of bead bugs of each color in the meadow in Data Table under the column "Before Predation" for the next generation.
7. Repeat steps 3 through 6 three times.

Data Table 1
Number of Bead Bugs

	Before Predation				After Predation			
	blue	yellow	pink	gray	blue	yellow	pink	gray
First generation	20	0	20	0				
Second generation								
Third generation								
Fourth generation								
Fifth generation								
Class average Fifth generation								

ERIC

Questions

1. What has happened to the number of blue beads in the meadow over four generations?

2. What has happened to the number of pink beads in the meadow over four generations?

3. How would you explain this difference?

4. Which color is adaptive, blue or pink?

5. What evidence indicates this color is an adaptive trait?

6. Do you think this color would be an adaptive trait in all meadows?

7. Was the mutation from blue to yellow an adaptive mutation?
   Why?

8. Was the mutation from pink to gray adaptive? Why?

ERIC Full Text Provided by ERIC

Commentary

1 & 2.

Students should have observed that one color of beads--blue, for example--increased in relative percentage, and that the other color (pink) decreased.

3. Students should be able to explain this difference by recognizing that (blue) beads have a reproductive advantage; few are seen and captured by birds before reproduction, while more of the (pink) beads are seen and eaten by birds before reproducing.

4 & 5.

The *only* evidence that is relevant from a biological perspective is that the (blue) beads produced more offspring. Answers focusing on how (blue) beads blend in with the meadow are irrelevant.

6. Students should recognize that blue would not be adaptive in *all* situations.

7 & 8.

Students should recognize that one mutation (for example, yellow) was not adaptive because individuals of this color tended to have poor survival rates.

Students should recognize that the other mutation was adaptive (for example, gray) because these individuals tended to have high survival rates.

9. Did any of the individual bead bugs change or adapt?

10. Did adaptation occur in your bead bug population?

11. What was the source of the new color traits in the population?

12. Do the environmental conditions in which a population lives affect the kind of mutation that occurs in the population?

13. What do you think would happen if the environment changed, for example, if the flowers in the meadow were mostly yellow?

14. Bead bugs vary in size as well as color. Over many generations, would you expect the average size of the individual bead bugs to change? Why or why not?

ERIC

9. Students should understand that no changes occurred in individual bead bugs.

10. Students should recognize that adaptation occurred in the population (e.g., that the population as a whole changed) even though the individuals in that population did not change.

11. Students should recognize mutation as the source of new colors.

12. Students should recognize that specific mutations are chance (random) occurrences and that the environment does not directly affect the number and kind of mutations which occur.

13. Students should recognize that if the environment changed, different traits would be adaptive (in the above example, the blue-to-yellow mutation would be adaptive) and that, through differential reproduction, the color composition of the populations would change over time.

14. Students may initially predict that smaller bead bugs would be harder for birds to see and, therefore smaller size would evolve. However, perceptive students may realize that size is not inherited (in this organism) and, therefore, cannot evolve.

ERIC

Data Table 2

Percent of Bead Bugs Which Survived to Reproduce

First Generation

	Blue	Pink
Class data		
Average		

Data Table 3

Numbers of Beads in Each Color in Population

Fifth Generation

	Blue	Yellow	Pink	Gray
Class data				
Average				

ERIC

V. Problem Sets

On the following two sheets a series of problem-solving exercises are presented to the students. These questions give students a chance to use newly acquired scientific conceptions to solve problems.

The format of the two problem sets is similar. Both begin with a question designed to address the value of variation of traits to the process of natural selection and the nature of adaptive traits. Since students possessing naive conceptions often do not recognize variation as important, this question is designed to create confusion followed by dissatisfaction with the naive conception.

Question #2 presents students with a natural selection example to work through. Students are given a hypothetical population and the particular selection pressure to which it is exposed. Students are led through this example by the use of key questions and, ultimately asked to predict and explain what will happen to that population.

Question #3 presents another problem for students to solve. In this case, however, students are given the end result of evolution by natural selection (a population possessing certain traits) and asked to explain how these traits evolved. In this question students are expected to provide explanations on their own. Students who have successfully completed Question #2 will be more likely to be able to do this.

Instructor feedback is crucial to the success of these problem sets as learning aids. These problems are often difficult for students because they require students to organize their newly acquired knowledge into a coherent scheme. It is completely possible for students to use their naive conceptions to solve these problems. It is suggested that instructors give students the opportunity to work through problems sets on their own (perhaps as a homework assignment) and then provide the necessary feedback in the form of class discussions or the like.

Problem Set 1: The Role of Natural Selection in Evolution

1. A commonly expressed cliche states that it is a good thing that humans are different from one another, otherwise everyone would be bored.

   Evolutionary biologists have a different explanation as to the value of variation in human populations.

   According to evolutionary theory, why is it good that humans are different from one another?

2. Suppose you have 2 beakers, each of which contained 100 mosquito larvae. To one of the beakers (Beaker A) you added a small amount of Insecticide (DDT) to the other (Beaker B) you added pure water. After 10 days you counted the number of dead mosquito larvae in each beaker.

   a. In which beaker would you expect to find more dead mosquito larvae? ___________
   b. Why?

   Now suppose you take the survivors of each beaker and allow them to breed with individuals in the same beaker. You then take the offspring and, again place them in beakers. You repeat the experiment, except in this case you place the same amount of insecticide in <u>both</u> beakers. Again you wait 10 days and count dead larvae.

   c. In which beaker would you expect to find more dead mosquito larvae?

   d. What difference in the way the two beakers were treated accounts for this?

   e. How do you explain this difference?

3. Domestic dogs today come in a variety of "styles." Different breeds show enormous variation in such things as size, color, hair length, etc. We know that all breeds were developed from ancestors which were very similar to modern wolves and coyotes.

   Using the dachshund as an example explain how this breed was produced from wolf-like ancestors.

Commentary

1. This question raises the issue of the value of variation in populations and the nature of adaptive traits. Students with correct understanding of the process of natural selection should be able to correctly explain the role variation plays in it. Students possessing naive conceptions often do not see this variation as relevant to natural selection, and therefore, cannot answer the question.

   Correct answers to the question should include a recognition of environmental conditions as determining the adaptiveness of any given trait. Students should recognize the variability of the human species both as a result of its ubiquitousness and as increasing the adaptibility of the species as a whole to future environments.

2. This question leads students step-by-step through an example of evolution by means of natural selection. Students are presented with two hypothetical populations of mosquitos initially under different environmental regimes (insecticide vs. none) and asked to predict what will happen to the two populations overtime.

   Instructors should be particularly attuned to student answers as it is possible to predict the correct result (i.e., evolution of resistance in Population A) in terms of the naive conception (a build up of immunity). Most students will correctly answer parts a-d, even if they possess naive conceptions.

   The key question, therefore, is Part e. To answer correctly students need to *use* the information in Questions a-d (that in generation #1, more mosquitos in the Insecticide Beaker A, will *die*, because of its poisonous effects than in the Noninsecticide Beaker B; that if both the second generation populations are exposed to insecticide, A will experience less mortality; and that the factor accounting for this difference is the first generation's exposure to insecticide) to explain the predicted result. Student answers should include *only* reference to differences in reproductive success of individuals possessing resistant versus succeptible traits in the two beakers. Student answers should *not* include reference to the *appearance* of the resistant trait such as "building of immunity" or "adapting to the insecticide."

3. This question asks students to use the concepts of evolution by means of natural selection to explain the existence of diverse traits in the dog species. Although, in this example, selection is artificial, students should recognize the essential similarities between this process and its natural counterpart.

   The form of this question ("How could daschunds evolve from wolf-like ancestors?") requires that students consider the source of novel traits. Students should recognize that traits such as the long-squat stature of the daschund arose by chance mutations and were preserved by selection on the part of human breeders.

Problem Set 2: Environmental Dependence of Adaptive Traits

1. Members of the species *Homo sapiens* (humans) exhibit striking variation in skin pigmentation. Compared to light-skinned individuals dark skinned people (a) are more resistant to sunburn, and (b) are less able to manufacture Vitamin D, an essential nutrient, when sunlight strikes their skin.

   a. Do you think that darkly pigmented skin is an adaptive trait in humans?

   b. Under what environmental conditions is darkly pigmented skin an adaptive trait?

      Not an adaptive trait?

   c. How do you think different skin pigmentation levels evolved in human populations?

2. Suppose that there are two populations of brown rabbits. The two populations belong to the same species. Population A lives in north Alaska, Population B lives in southern Florida. Suppose geneticists have determined that occasionally a mutation occurs in this rabbit species which results in a white-coated offspring.

   a. Would you expect the rates of the brown-white mutation be different in the two populations?

   b. Why?

   c. Predict what would happen to these two populations over time.

   d. Explain your reasoning.

Commentary

1. This problem touches on the issue of variation in populations by addressing the issue of the nature of adaptive traits.

Students should recognize that the environment determines the adaptiveness of any given trait. Students usually have little trouble recognizing the adaptation of different skin pigmentation levels to different environment (Parts a and b). However answers to Part c, which asks students to explain how different pigment levels evolved, will reveal whether students understand that the "adaptiveness" of a trait refers to the role of that trait in increasing an individuals chances of surviving and reproducing. Students possessing naive conceptions may simply explain this phenomenon by explaining that different races "adapted" to their environment or "needed to be a certain color."

2. This question presents an example of natural selection to students. Students are given two hypothetical populations of rabbits in two different environments. Questions a and b ask students to predict whether the appearance of white individuals will be dictated by the environment. Most students quickly understand that mutations are the result of chance occurrences and therefore correctly predict that the mutation rate will be the same for both populations.

Part c asks students to predict the evolution of the two separate populations. Again, most students correctly predict the outcome.

The key answer to this question is Part d (explain your reasoning). Since students have been given the source of changes in traits (occasional mutations to white color), students should recognize that change (or lack of change) in each population is due to selection by the environment. Students possessing naive conceptions may explain the correct prediction in a naive way. "Rabbits in Alaska need to be white" or "The rabbits adapted to their environments."

3. When penicillin was first discovered in 1939, it was hailed as a "miracle cure." Today, several populations of bacteria exist that are resistant to (not killed by) penicillin. These strains did not exist when penicillin was first discovered. How did resistant strains of bacteria come into being?

ERIC

3. This question presents students with a documented example of modern-day evolution: resistance to antibiotics in bacteria. In order to correctly explain this phenomenon, students must use all the issues of evolution by natural selection correctly. Students must postulate the existence of mutations resulting in resistant individuals and must explain the existence of differential survival of resistant individuals when exposed to antibiotics.

It is very easy for students to use naive conceptions to explain bacterial resistance. The most often-used concept is "immunity" (Bacteria gradually built up immunity.) Instructors should point out that the concepts of immunity and resistance are very different and that immunity, since it is an acquired trait, cannot be passed to offspring.