Evolution by Natural Selection

1. Mice Living in a Desert

These drawings show how a population of mice on a beach changed over time.

1. Describe how the population of mice is different in figure 3 compared to figure 1. Explain what happened to cause this difference.

In discussing evolution, **fitness** is defined as the ability to survive and reproduce.

2. For the mice in the figure, which characteristic increased fitness?

3. The term fitness can have two different meanings, depending on what subject you are discussing. Answer the following questions to show the two different meanings of fitness.

   What does the term fitness mean when biologists are discussing evolution?

   What does the term physical fitness mean?

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1 Adapted from the University of California, Los Angeles, Life Sciences 1 Demonstration Manual by Drs. Ingrid Waldron and Jennifer Doherty, Dept Biology, University of Pennsylvania. © 2017. Teachers are encouraged to copy this Student Handout for classroom use. A Word file (which you can edit if you want), a one-habitat version of the activity, and Teacher Preparation Notes with instructional suggestions and background information are available at [http://serendip.brynmawr.edu/exchange/waldron/naturalselection](http://serendip.brynmawr.edu/exchange/waldron/naturalselection)
A characteristic which is influenced by genes and passed from parents to offspring is called a heritable trait. For example, fur color is a heritable trait for mice.

An adaptation is a heritable trait that increases fitness.

4. This table describes the characteristics of a population of mice living on gray sand.

<table>
<thead>
<tr>
<th>Color of Fur</th>
<th>White</th>
<th>Gray</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average running speed</td>
<td>5 cm/sec.</td>
<td>6 cm/sec.</td>
<td>8 cm/sec.</td>
</tr>
<tr>
<td>Average number of offspring</td>
<td>5</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Average age at death</td>
<td>3 months</td>
<td>6 months</td>
<td>3 months</td>
</tr>
</tbody>
</table>

Which color fur is an adaptation for these mice? What evidence supports your conclusion?

Over time, an adaptation tends to become more common in a population.
- Because the adaptation increases fitness, individuals with this trait generally produce more offspring.
- Because the trait is heritable, offspring generally have the same trait as their parents. Therefore, over time, the adaptation tends to become more common in the population. This process is called natural selection.

This figure shows what would happen if a population of mice on gray sand began with a pair of white mice, a pair of gray mice, and a pair of black mice.

Notice that:
- For the Generation 1 adults, 2/6 = 33% had gray fur.
- For the Generation 2 babies, 15/28 = 54% had gray fur.

5. Explain why the percent of mice with gray fur increased from Generation 1 adults to Generation 2 babies. Include these terms in your answer: adaptation, fitness and natural selection.
6a. For the mice on the gray sand, what do you think would happen after many generations?
   a. About half of the mice (54%) would have gray fur.
   b. Almost all of the mice would have gray fur.
   c. There would be equal numbers of mice with white fur, gray fur and black fur.

6b. Explain your reasoning.

7a. Now think about a population of mice living on white sand. Suppose the population began with a pair of white mice, a pair of gray mice, and a pair of black mice. After many generations, almost all of the mice in this population would have ________ fur.
   (white/gray/black)

7b. When mice live on white sand, which color fur is an adaptation?

7c. When mice live on gray sand, which color fur is an adaptation?

Notice that different characteristics increase fitness in different environments. Therefore, a characteristic that is an adaptation in one environment may not be an adaptation in a different environment.

8. Explain how natural selection is occurring in the example shown in these drawings.

A deer eats from the cactus that doesn't have thorns.
A few weeks later the cactus with thorns has flowers.
A few months later, baby cactus plants have grown from the seeds produced by the flowers.
II. Simulation of Natural Selection

Next, you will play a simulation game to demonstrate how natural selection works. A simulation is a good way to mimic and simplify the process so we can understand how evolution by natural selection works. This simulation involves two populations of pom-poms. One population lives in a Black Forest habitat and the other population lives in a Red Grassland habitat. The only threat to the pom-pom creatures is the presence of ravenous hunters (that’s you!).

Each pom-pom is either red or black, and each hunter will have either a fork or spoon as his or her feeding structure. The differences in pom-pom color and hunter feeding structures are heritable. If a pom-pom survives to reproduce, its offspring will have the same color as their parent. Similarly, if a hunter survives to reproduce, his or her offspring will have the same feeding structure as their parent.

9. Your teacher will scatter an equal number of black and red pom-poms on the Black Forest and on the Red Grassland. Which color pom-pom do you think will be more likely to be captured and eaten in each habitat?

   Black Forest _________   Red Grassland _________

Explain the reasons for your predictions.

10. You will be given a feeding structure (a fork or spoon) and a cup which will serve as your “stomach”. To capture a pom-pom, you must use only your fork or spoon to lift the pom-pom from the habitat and put it into your cup. Which feeding structure do you think will allow a hunter to capture more pom-poms in each habitat?

   Black Forest (represented by a rough black material such as faux fur) _____________
   Red Grassland (represented by a red fleece material) ________________

Explain the reasons for your predictions.

Simulation Procedure

- Go to your assigned habitat: Black Forest or Red Grassland.
- Rules for Feeding:
  - Start and stop when your teacher says to.
  - You must pick up each pom-pom with your feeding implement and drop it into your cup. You may not tilt your cup and scoop pom-poms into your cup.
  - Once a pom-pom is on a classmate’s fork or spoon it is off limits.
- After feeding, count how many pom-poms you have eaten and line up with your classmates who were feeding on the same habitat, from fewest pom-poms eaten to most pom-poms eaten. Then, follow the instructions of the Student Helper for your group.
While your teacher is busy helping the surviving pom-poms to reproduce on each habitat, discuss the following questions with your group:

- Which feeding structure contributed to greater fitness in your habitat?
- What characteristics of forks and spoons increased or decreased fitness in your habitat?

Next, you will run through the simulation one more time.

11. Evaluate the data for number of hunters with spoon vs. fork feeding structures in each habitat. Were there any changes from generation 1 to generation 3? If yes, describe the change or changes and propose possible explanations.

12. Copy the pom-pom data from the table displayed by your teacher into the table below. Then, for each generation of pom-poms in each habitat, calculate the percent of each color.

<table>
<thead>
<tr>
<th></th>
<th>Pom-poms in the Black Forest</th>
<th>Pom-poms in the Red Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black</td>
<td>Red</td>
</tr>
<tr>
<td>Generation 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Generation 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Generation 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

13. Use the data in the table to complete the following graphs. This will help you see the trends in the percent of pom-poms of each color over the three generations in each habitat.
14a. For each habitat, describe whether one color pom-pom became more common while the other color pom-pom became less common.

Black Forest:

Red Grassland:

14b. At the beginning of the simulation, the pom-pom populations were half red and half black in both the Black Forest and the Red Grassland. Explain why the trends in pom-pom colors differed in the two different habitats.

15. Did any individual pom-poms change color? yes ___  no ___
If no, then why did the colors of the pom-poms in the final populations differ from the colors of the pom-poms in the original populations?

Notice that natural selection does not refer to individuals changing. Rather, as a result of natural selection, the frequency of adaptations in a population increases.

16a. Suppose that the black forest experienced a prolonged drought so all the trees died and the habitat became red grassland. What do you think would happen to the pom-pom population? First, make your prediction if the population of pom-poms in the black forest at the beginning of the drought included both red and black pom-poms.

16b. Next, think about an alternative scenario. Suppose that natural selection over many generations had eliminated all the red pom-poms in the black forest habitat so only black pom-poms survived. After that, a prolonged drought resulted in this habitat turning into a red grassland. Would natural selection for pom-pom color occur? Why or why not?

16c. Based on this example, explain why evolution by natural selection can only occur if there is variation in a trait.
17a. Suppose that your class repeated the simulation, but this time all the hunters were blindfolded so they could only find pom-poms by touch. For each habitat, predict the proportions of red and black pom-poms in the population at the end of the simulation. (Remember that at the beginning of the simulation half the pom-poms were red and half were black.)

**Black Forest:**

**Red Grassland:**

17b. Explain your reasoning.

17c. Based on this example, explain why evolution by natural selection can only occur if the variation in a trait results in differences in fitness.

18a. Next, think about what would happen if your class repeated the simulation, this time with hunters who could see, but pom-pom color would not be heritable. For red pom-pom parents and for black pom-pom parents, half of the offspring would be red and half would be black. Predict the proportions of red and black pom-poms in the population in each habitat at the end of the simulation.

**Black Forest:**

**Red Grassland:**

18b. Based on this example, explain why evolution by natural selection can only occur if the variation in a trait is heritable.

This simulation provides a useful basis for understanding many aspects of natural selection. However, it is important to note that, because a simulation necessarily simplifies the process that it mimics, there will be important differences between the simulation and the actual biological process. For example:

- In our simulation visual predation was the only factor that influenced mortality and reproduction of the pom-poms. In contrast, for real biological organisms, mortality is influenced by additional factors (e.g. infection) and reproductive success is influenced by other factors in addition to survival.
- Also, in our simulation, each offspring had the exact same characteristic as its only parent, but, for most biological organisms, some of the offspring will have different characteristics than their parents.

Because of these differences between our simulation and reality, natural selection would be slower in real biological populations. You will see an example of this in the next section.
III. Natural Selection in Action – The Peppered Moth

These photos both show the two major forms of the peppered moth. Can you find the speckled form of the peppered moth on the lichen-covered tree trunk shown below? Can you find the black form of the peppered moth on the tree trunk that has been darkened by air pollution?

Peppered moths are active at night. During the day peppered moths rest on tree trunks and branches. Some of these resting moths are eaten by birds.

19a. Researchers have found differences in mortality for the speckled and black forms of the peppered moth in different types of environment.

Which form of the peppered moth do you think had higher mortality in forests in unpolluted areas where tree trunks and branches are lighter? ___black     ___ speckled

Which form of the peppered moth do you think had higher mortality in forests in areas where air pollution had resulted in dark tree trunks and branches? ___ black     ___ speckled

19b. Explain your reasoning.

20. An individual peppered moth cannot change from black to speckled or vice versa. The difference between the black and speckled forms of the peppered moth is a heritable trait; specifically, this difference results from different alleles of a single gene. The allele for the black form (B) is dominant over the allele for the speckled form (b).

In these Punnett squares, circle the genotype of each parent and offspring that would have the black form. Based on these Punnett squares, explain why the offspring of peppered moths generally look like their parents.

\[
\begin{array}{ccc}
\text{b} & \text{b} & \text{B} \\
\text{b} & \text{bb} & \text{BB} \\
\text{b} & \text{bb} & \text{BB} \\
\text{B} & \text{Bb} & \text{Bb} \\
\end{array}
\]
**21.** In the first column of this table, state three necessary conditions for evolution by natural selection to occur. (Hint: See questions 16c, 17c and 18b.) In the second column, explain the evidence that each of these necessary conditions is satisfied by the black vs. speckled forms of the peppered moth.

<table>
<thead>
<tr>
<th>Natural selection can only occur if:</th>
<th>What is the evidence that the peppered moth example meets this necessary condition?</th>
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Natural selection has occurred in peppered moth populations. The black form of the peppered moth was very rare in England before 1850. After that date, industrialization resulted in air pollution which darkened tree trunks and branches. In industrialized areas with dark tree trunks and branches, the frequency of black peppered moths increased and speckled peppered moths became rare. The trend in southeastern Michigan was similar, although industrialization began later; no black peppered moths were observed before 1929; by the 1950s more than 90% of peppered moths were black.

Beginning in the late 1950s, government regulation resulted in decreased air pollution. Consequently, tree trunks and branches became lighter. As would be expected, there was a decrease in the percent of peppered moths that were black. This decrease is shown for one area in England (black dots) and one area in Michigan (diamonds for 1959-1962 and 1994-1995).

The open circles in the graph represent the trend predicted by a model of natural selection which incorporated experimental estimates of higher mortality rates for black peppered moths in unpolluted environments. 

(http://jhered.oxfordjournals.org/content/87/5/351)
22. Which characteristic was an adaptation for peppered moths in industrialized areas with dark tree trunks and branches?  ___ black form       ___ speckled form

Which characteristic is an adaptation for peppered moths in unpolluted areas with lighter tree trunks and branches?  ___ black form       ___ speckled form

23. A student wrote the following explanation of the trends in England.  
When air pollution resulted in dark tree trunks and branches, the peppered moths needed to be dark so they would not be seen and eaten by birds. Therefore, after 1850 most of the peppered moths became black. Then, air pollution was reduced so tree trunks and branches were lighter, and the peppered moths needed to be lighter so they would not be eaten by birds. Therefore, after 1950 most of the peppered moths became speckled.

Write a scientifically more accurate explanation of what happened to cause the trends in the proportions of black vs. speckled peppered moths.

24a. Many people think of the process of evolution as "survival of the fittest". How do you think most people interpret "survival of the fittest"?

24b. Compare and contrast the common conception of survival of the fittest with the scientific definition of which organisms are the fittest in terms of natural selection.

25. Use the peppered moth example to illustrate the following generalization:
   Natural selection acts on individuals, but only populations evolve.