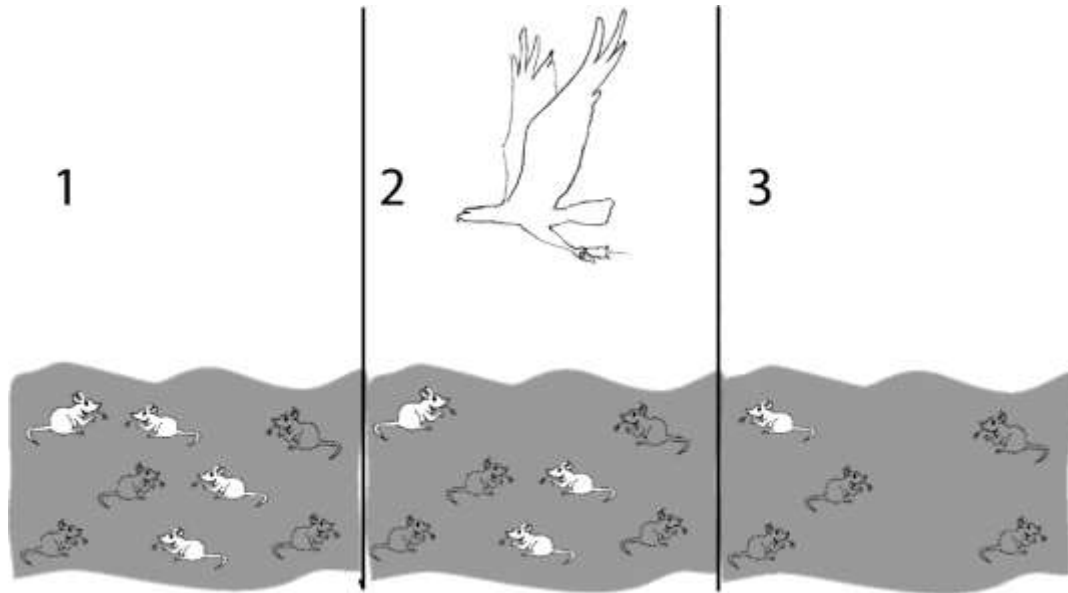


Evolution by Natural Selection¹

I. What is evolution by natural selection?

A population of mice lived in a desert with gray sand. These drawings show how the population changed from time 1 to time 3.



1a. Describe how the population of mice was different at time 3 compared to time 1. Explain what happened to cause this difference.

1b. Suppose the mice in drawing 3 had babies. What color fur do you think most of the babies would have? Explain your reasoning.

Next, you will learn some vocabulary that is useful for analyzing how populations change and why.

- **Evolution** is defined as a change over time in the inherited characteristics of a population.
- **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.

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

What does the term physical fitness mean?

¹ By Drs. Ingrid Waldron and Jennifer Doherty, Dept Biology, University of Pennsylvania. © 2018. Teachers are encouraged to copy this Student Handout for classroom use. A Word file, alternative versions of the simulation, and Teacher Preparation Notes with instructional suggestions and background information are available at <http://serendip.brynmawr.edu/exchange/waldron/naturalselection>

A biologist released three pairs of adult mice in a gray sand desert that did not have any other mice. These Generation 1 adults and their Generation 2 babies are shown in this chart. For the Generation 1 adults, $2/6 = 33\%$ had gray fur. For the Generation 2 babies, $15/28 = 54\%$ had gray fur.



This table shows some characteristics of the Generation 1 female mice.

	White Fur	Gray Fur	Black Fur
Running speed	5 cm/sec.	6 cm/sec.	7 cm/sec.
Number of babies	5	15	8
Age at death	3 months	6 months	4 months

4. What do you think is the reason why the female mouse with gray fur had the most babies?

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.

5a. Which color fur is an adaptation for these mice? What evidence supports your answer?

5b. Explain why this adaptation was more common in the Generation 2 babies than in the Generation 1 adults.

6a. What do you think would happen to this population of mice after many generations on the gray sand?

- About half of the mice (54%) would have gray fur.
- Almost all of the mice would have gray fur.
- There would be equal numbers of mice with white fur, gray fur and black fur.

6b. Explain your reasoning.

7a. Suppose that when the Generation 2 mice became adults, six of them migrated to a nearby desert with white sand. Which color fur would be an adaptation for the mice on the white sand?

7b. Is the same color fur an adaptation in all environments? yes ___ no ___

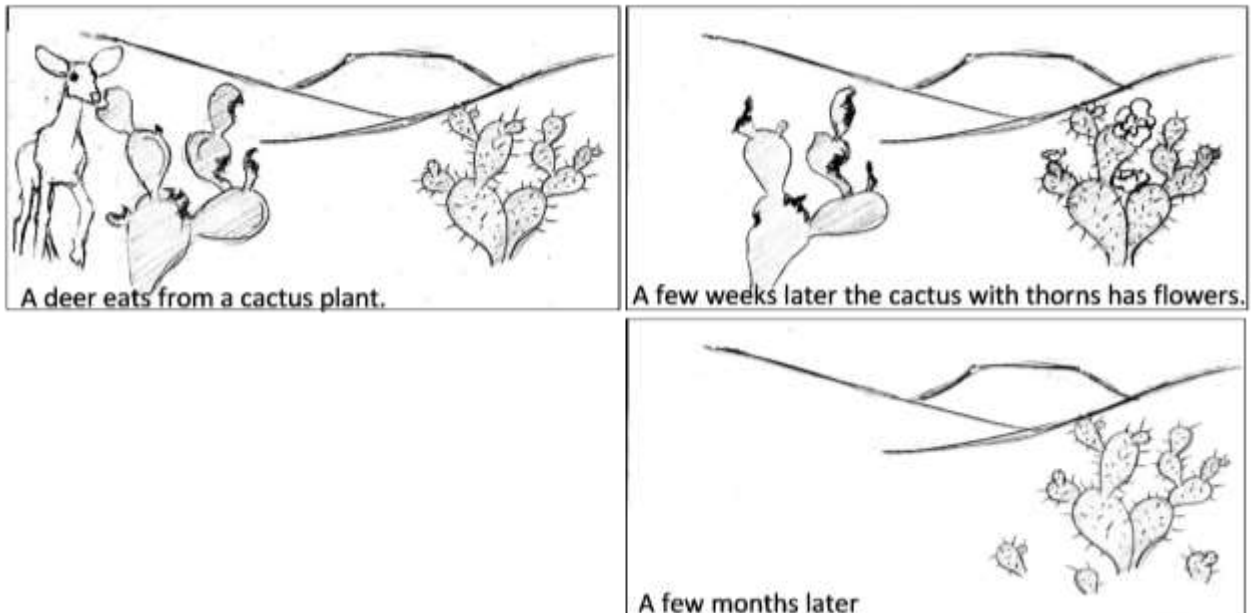
7c. Suppose that the mice that migrated to the white sand included two black mice, two gray mice, and two white mice. What do you think the population of mice on the white sand would look like after many generations? Explain your reasoning.

In questions 4-7, you have seen that, over time, an adaptation becomes common in a population of mice. As you know, an adaptation is a heritable trait that increases fitness.

8. Explain why a trait that is heritable and increases fitness becomes common in a population of any type of animal or plant.

The process you described in your answer to question 8c is called **natural selection**. Due to natural selection, an adaptation tends to become common in a population.

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



II. Simulation of Natural Selection

Now, you will play a simulation game to show how 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 these pom-pom creatures is the presence of ravenous hunters (that's you!).

Each pom-pom is either red or black. 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, the hunter's offspring will have the same feeding structure as their parent.

10. At the beginning of the simulation, each pom-pom population will have 50% red pom-poms and 50% black pom-poms. How do you think the percent red vs. black pom-poms will change after you and your classmates have hunted for pom-poms?

Black Forest:

Red Grassland:

Explain the reasons for your predictions.

11. You will be given a fork or spoon as your feeding structure and a cup 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. For each habitat, indicate which feeding structure you think will allow a hunter to capture more pom-poms or indicate if you think the two different types of feeding structures will work equally well.

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 structure and drop it into your cup. You may **not** tilt your cup and scoop in pom-poms.
 - 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.

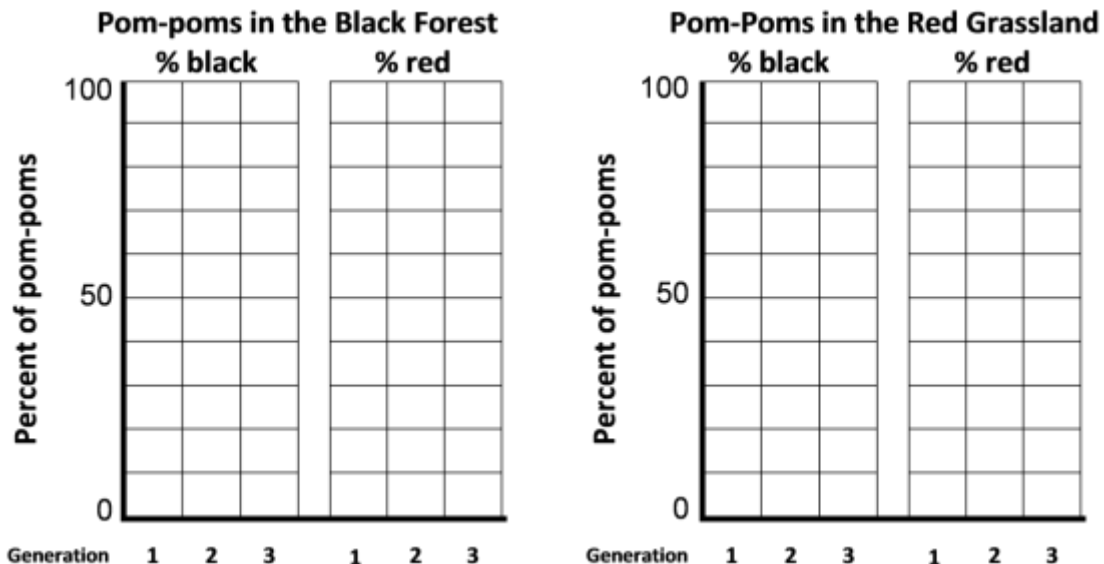
- While your teacher is busy helping the surviving pom-poms to reproduce on each habitat, discuss the following questions with your group:
 - Which feeding structure contributed to greater fitness in your habitat?
 - What characteristics of forks and spoons increased or decreased fitness in your habitat?
- Next, you will run through the simulation one more time.

12. Evaluate the class data for number of hunters with spoon vs. fork feeding structures in each habitat. Describe any changes from generation 1 to generation 3. Do the trends in the class data match your predictions in question 11? Propose possible explanations for the trends or lack of trends in the class data for each habitat.

13. Copy the class pom-pom data into the table below. Then, for each generation of pom-poms in each habitat, calculate the percent of each color.

	Pom-poms in the Black Forest				Pom-poms in the Red Grassland		
	Black	Red	Total		Black	Red	Total
<u>Generation 1</u> Number							
Percent	50%	50%	100%		50%	50%	100%
<u>Generation 2</u> Number							
Percent			100%				100%
<u>Generation 3</u> Number							
Percent			100%				100%

14. Use the data in the table to complete the following graphs.



15a. For each habitat, describe the changes in the percent red vs. percent black pom-poms. Do the results of your simulation match your predictions in question 10?

Black Forest:

Red Grassland:

15b. 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.

16. 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 their characteristics. Rather, natural selection results in a higher proportion of individuals that have an adaptation.

17a. 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.

17b. Next, think about a different scenario. Suppose that natural selection over many generations had eliminated all the red pom-poms in the black forest habitat so the population in this habitat only had black pom-poms. 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?

17c. Based on this example, explain why evolution by natural selection can only occur if there is variation in a trait.

18a. Suppose that your class repeated the simulation, but this time all the hunters were blind-folded 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:

18b. Explain your reasoning.

18c. Based on this example, explain why evolution by natural selection can only occur if the variation in a trait results in differences in fitness.

19a. 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. No matter what color the pom-pom parent was, 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:

19b. Based on this example, explain why evolution by natural selection can only occur if the variation in a trait is heritable.

20. This simulation helps us to understand the basic process of natural selection. However, a simulation simplifies the biological process that it mimics, so there will be differences between the simulation and the actual biological process. Describe one way that natural selection in real biological populations is more complex than our simulation.

III. Natural Selection and the Peppered Moth

Scientists have observed natural selection in action in multiple types of animals, plants and microorganisms. You will analyze one example – natural selection in peppered moths.

Both of these photos show the two major forms of peppered moth. Can you find the speckled form of the peppered moth on the lichen-covered tree trunk shown below? Can you find the dark form of the peppered moth on the dark tree trunk?



In rural areas with little air pollution, many tree trunks were covered with lichen.



In industrial areas with heavy air pollution, most tree trunks were dark.

Peppered moths are active at night. During the day, peppered moths rest on tree trunks and branches. Some of these resting peppered moths are eaten by birds. Researchers have found that the speckled form of the peppered moth has higher mortality and lower fitness in one type of environment and the dark form has higher mortality and lower fitness in the other type of environment.

21. In each photo, circle the form of the peppered moth that would have higher mortality and lower fitness in that environment.

An individual peppered moth cannot change from speckled to dark or vice versa. The difference between the speckled and dark forms of the peppered moth is a heritable trait. Specifically, this difference results from different alleles of a single gene. The allele for the dark form (**D**) is dominant over the allele for the speckled form (**d**).

22a. In these Punnett squares, circle the genotype of each parent and offspring that would have the dark form. Put an * next to the genotype of each parent or offspring that would have the speckled form.

	d	d
d	dd	dd
d	dd	dd

	D	D
D	DD	DD
D	DD	DD

	D	d
D	DD	Dd
d	Dd	dd

22b. Explain why the offspring of peppered moths generally look like their parents.

23. Complete this table to describe three necessary conditions for evolution by natural selection to occur and the evidence that the peppered moth example fulfills these conditions.

Three Necessary Conditions for Evolution by Natural Selection to Occur (Hint: See questions 17c, 18c and 19b.)	What is the evidence that the peppered moth example fulfills each necessary condition? (Hint: See page 8.)

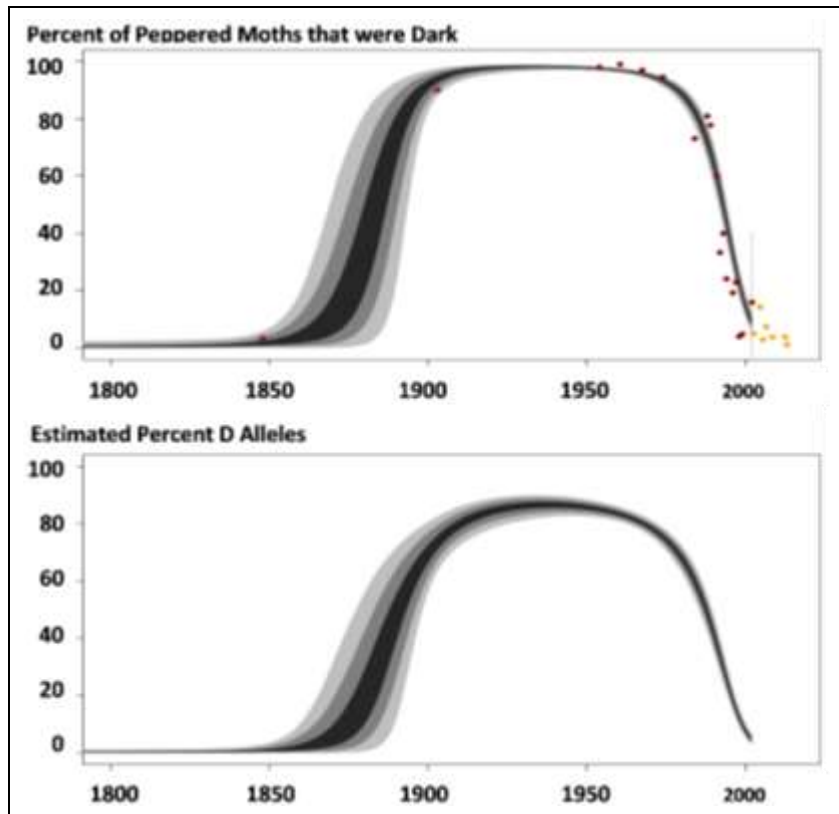
24. Complete this table to describe the expected effects of natural selection as the environment changed in regions of England that became industrialized.

Environmental Change for Industrialized Regions of England	Expected Effects of Natural Selection on Trends in % Dark Peppered Moths	Expected Trends in % D Alleles (for the D/d gene that determines the dark vs. speckled form)
Before 1850, air pollution was low and tree trunks and branches were lighter and often covered with lichen.	The dark form of the peppered moth was more likely to be eaten by birds, so the dark form had low fitness and was very rare.	Moths with the D allele are dark. In this environment, dark moths rarely survived to reproduce. Therefore, the D allele was very rare.
After 1850, industrialization resulted in air pollution which darkened tree trunks and branches.		
Beginning in the late 1950s, government regulation resulted in decreased air pollution, so tree trunks and branches became lighter.		

These graphs show trends in an industrialized region in England. Each dot in the upper graph represents a data point. The lines show the estimated trends. (The width of each line indicates uncertainty in the estimates.)

25a. If there are differences between the trends in these graphs and your predictions in questions 24, use the results shown in these graphs to correct your answers to questions 24.

25b. Explain why the **D** allele became more common after 1850 and then became less common after 1950.



26a. For each time period, how big was the difference in the percent of peppered moths that were dark?

For 1950 vs. 1850, this difference was close to 0% 50% 100% .

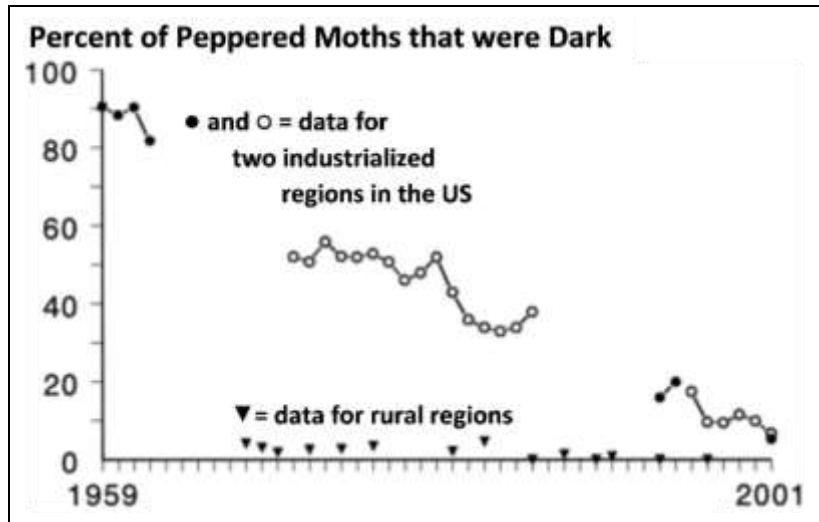
For 2000 vs. 1800, this difference was close to 0% 50% 100% .

26b. Explain the reasons why the difference in percent dark was so small for one of these time periods and much bigger for the other time period.

27. Explain how the peppered moth example illustrates the general principle that: Natural selection acts on individuals, but only populations evolve.

In the US, as in England, the percent of peppered moths that were dark increased as air pollution increased in industrializing regions. Beginning in the late 1950s, air pollution was reduced, and the percent of peppered moths that were dark decreased in industrialized regions.

In rural regions, air pollution remained low and dark peppered moths were never common.



28. A student wrote this paragraph to explain the causes of the trends in this graph.

Most of the peppered moths in the industrial regions were dark in 1959 because air pollution had resulted in dark tree trunks and branches so the peppered moths needed to be dark so they would not be seen and eaten by birds. After 1959, air pollution was reduced, so tree trunks and branches became lighter. The peppered moths became lighter so they would not be eaten by birds. In rural regions, there was little air pollution, so the tree trunks and branches were lighter and peppered moths did not need to become dark.

Write a scientifically more accurate explanation of what happened to cause the trends in the graph.

29a. Many people think of the process of evolution as "survival of the fittest". How do you think most people interpret "survival of the fittest"?

29b. Contrast the common conception of survival of the fittest with the scientific definition of which organisms are the fittest in terms of natural selection. Include examples of characteristics that contribute to fitness in plants as well as animals.