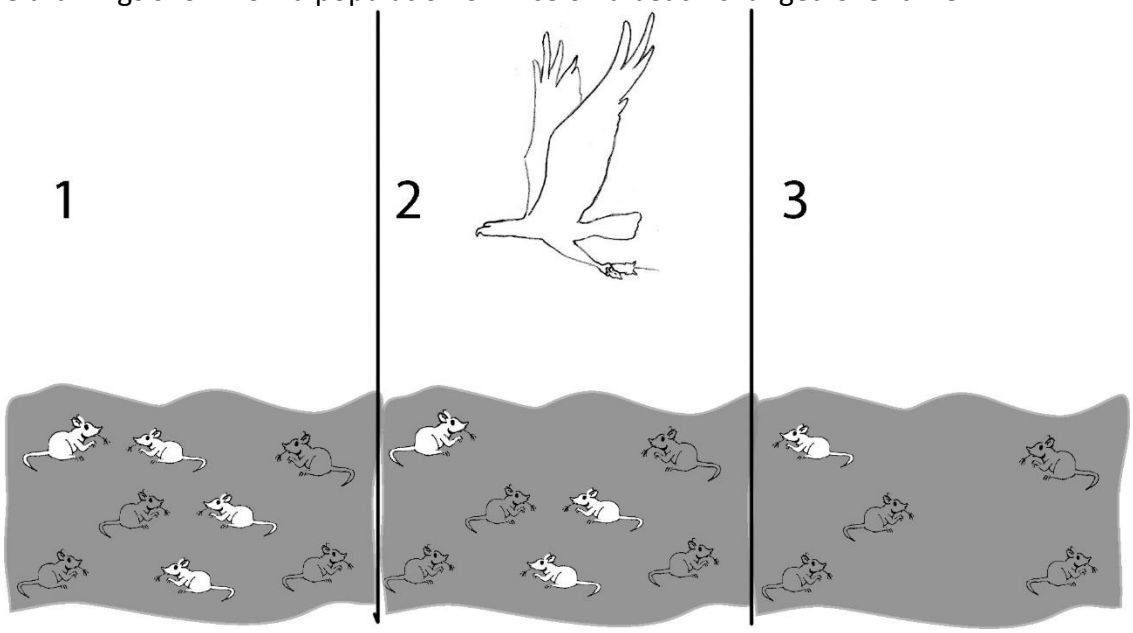
Evolution by Natural Selection[1]

I. 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.

An **adaptation** is any characteristic that increases **fitness**, which is defined as the ability to survive and reproduce.

2. For the mice in the figure, what characteristic was an adaptation that 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?

[1] Adapted from the University of California, Los Angeles, Life Sciences 1 Demonstration Manual by Drs. Jennifer Doherty and Ingrid Waldron, Dept Biology, University of Pennsylvania. © 2016. 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

Suppose a population had three female mice with the following characteristics.

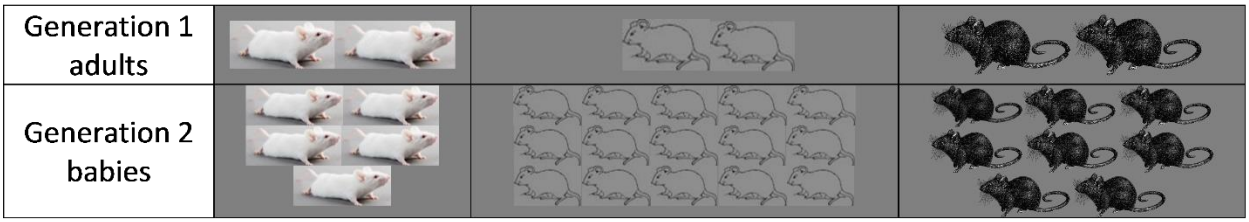
Color of Fur	White	Gray	Black
Running speed	5 cm/sec.	6 cm/sec.	8 cm/sec.
# offspring produced by each female	5	15	8
Age at death	3 months	6 months	3 months

4. From an evolutionary point of view, which mouse would be the fittest? How do you know that this mouse would be the fittest?

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.

A heritable trait that increases fitness is called an **adaptive heritable trait**. Individuals with an adaptive heritable trait generally produce more offspring than individuals that do not have this trait. For example, on gray sand, gray fur color is an adaptive heritable trait which allows mice to survive longer and have more litters of baby mice.

This figure shows what would happen if a population of mice in an area of gray sand began with a pair of white mice, a pair of gray mice, and a pair of black mice in generation 1. Because the gray mice survive longer and have more babies, the percent of mice with gray fur increases from 33% of the generation 1 adults to 54% of the generation 2 babies.



5a. Which type of baby mouse would be most likely to survive to become an adult who reproduces? ___ white ___ gray ____ black

5b. For generation 2 adults, would you expect the percent gray to be

___ <54% ____ 54% ___ >54%?

5c. Explain why the percent of adult mice with gray fur would increase from generation 1 to generation 2. Include differences in survival and reproduction in your explanation. Also, include the terms fitness and adaptive heritable trait in your answer.

6a. A population of mostly gray mice living on a patch of gray sand are asleep in their burrows. While the mice are sleeping, the gray sand is replaced by white sand. (Perhaps the owner of the desert has a plan to attract more tourists.) Think about what would happen to the population of mice on the white sand. After several generations, most of the mice would have _____ fur.
(white/gray/black)

6b. Explain how the change in the color of the sand could result in a change in the most common fur color in this population of mice.

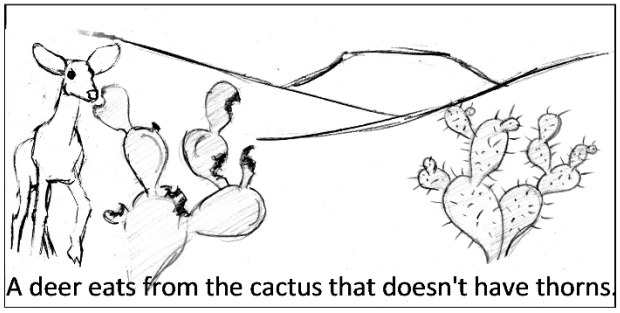
7. When mice live on gray sand, which color fur is an adaptive heritable trait?

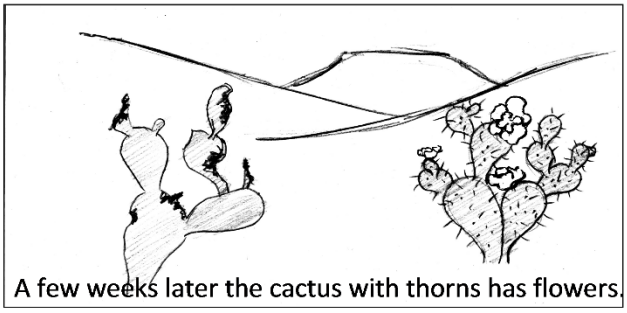
When mice live on white sand, which color fur is an adaptive heritable trait?

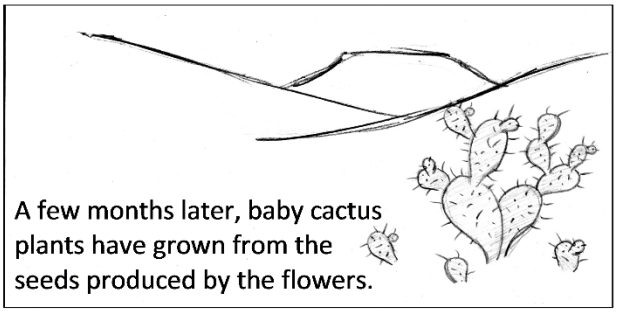
Is the same trait adaptive in both environments?

These examples illustrate how, over time, an adaptive heritable trait tends to become more common in a population. Because the trait is adaptive, 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 adaptive heritable trait tends to become more common in the population. This process is called **natural selection**.

8. Explain how these drawings illustrate an example of natural selection. Include the term "adaptive heritable trait" in your answer.


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 in real populations. 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. The offspring of a pom-pom that survives to reproduce has the same color as its parent. Similarly, the offspring of a hunter that survives to reproduce has the same feeding structure as his or her 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.

<u>Simulation Procedure</u>

- 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.

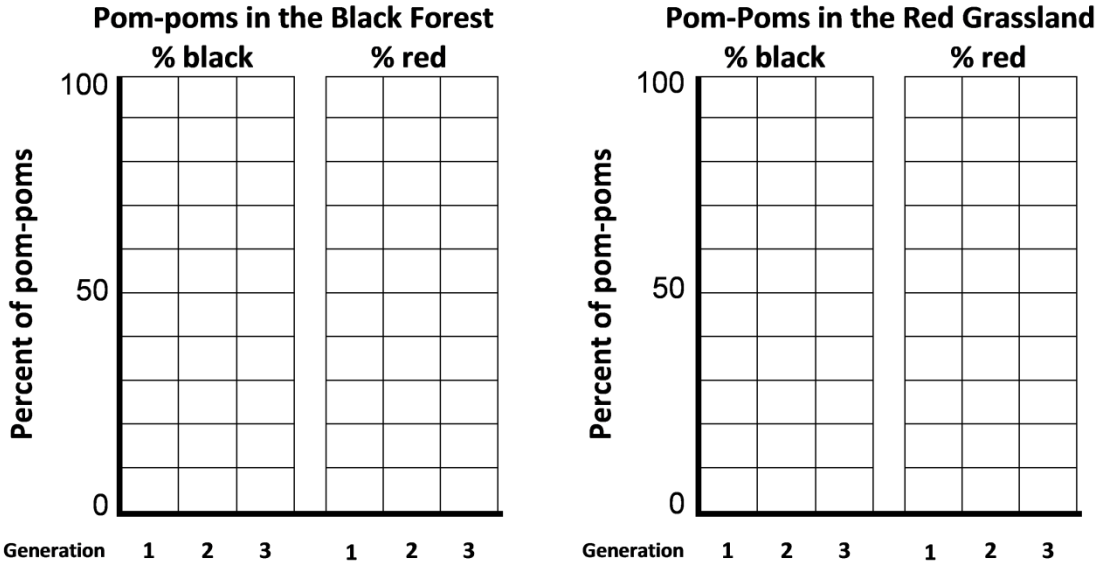
- While your teacher is busy helping the surviving pom-poms to reproduce on each habitat, discuss the following questions with your group:
  - Which feeding structure contributed to greater fitness in your habitat?
  - What characteristics of forks and spoons increased or decreased fitness in your habitat?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

11. For each habitat, evaluate the data on the board that shows number of hunters with spoon vs. fork feeding structures. Were there any changes from generation 1 (the beginning of the simulation) to generation 3 (the end of the second cycle)? 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.

	Pom-poms in the Black Forest				**Pom-poms in the Red Grassland**		
	Black	Red	Total		Black	Red	Total
Generation 1 Number							
Percent			100%				100%
Generation 2 Number							
Percent			100%				100%
Generation 3 Number							
Percent			100%				100%

13. Use the data to complete the following graphs. This will help you to 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 these two different habitats.

15. Did any individual pom-poms change color or adapt? If not, 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 <u>not</u> refer to individuals changing. Rather, the frequency of adaptive heritable traits in a population changes as a result of natural selection.

16a. What do you think would happen to the pom-pom population if the black forest experienced a prolonged drought so all the trees died and the habitat became red grassland? First, make your prediction of what would happen 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 blind-folded so they could only find pom-poms by touch. For each habitat, predict the proportion 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.

18. Next, think about what would happen if your class repeated the simulation with hunters that could see, but pom-pom color was not heritable. In other words, the color of pom-pom offspring would not be related to the color of their parents. No matter how many pom-pom parents were red or black, half of the offspring would be red and half would be black. 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 phenotype 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 genotypes of all parents and offspring that would have the black phenotype. Based on these Punnett squares, explain why peppered moths generally have offspring that look like their parents.

	b	b
b	bb	bb
b	bb	bb

	B	B
B	BB	BB
B	BB	BB

	B	b
B	BB	Bb
b	Bb	bb

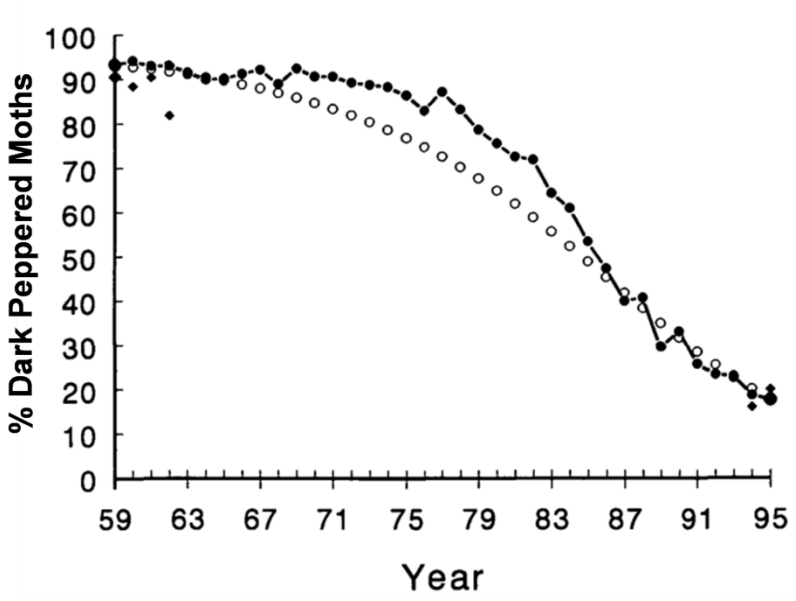
21. In the first column of this table, state three necessary conditions for evolution by natural selection to occur. (Hint: See questions 16c, 17c and 18.) In the second column, explain the evidence that each of these necessary conditions is satisfied by the black vs. speckled forms of the peppered moth.

Natural selection can only occur if:	What is the evidence that the peppered moth example meets this necessary condition?

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 (black 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 trait was an adaptive heritable trait for peppered moths in industrialized areas with dark tree trunks and branches? ___ black form ___ speckled form

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

23. A student wrote the following explanation of what caused the increase in the black form of the peppered moth after 1850 and then the decrease in the black form after 1950.

> When air pollution resulted in dark tree trunks and branches, the peppered moth needed to be dark so it would not be seen and eaten by birds. When air pollution was reduced so tree trunks and branches were lighter, the peppered moth needed to be lighter so it would not be eaten by birds.

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