

ALLELE AND PHENOTYPE FREQUENCIES IN ROCK POCKET MOUSE POPULATIONS

OVERVIEW

This lesson serves as a supplement to the short film *The Making of the Fittest: Natural Selection and Adaptation* (<http://www.hhmi.org/biointeractive/making-fittest-natural-selection-and-adaptation>) by reinforcing the concepts of variation and natural selection. If your class does not cover Hardy-Weinberg equilibrium, you may wish to use another lesson, "Color Variation over Time in Rock Pocket Mouse Populations" (<http://www.hhmi.org/biointeractive/color-variation-over-time-rock-pocket-mouse-populations>).

KEY CONCEPTS AND LEARNING OBJECTIVES

- Mutations that increase fitness of an organism increase in frequency in a population.
- Evolution can happen quickly (hundreds of years, or even less); advantageous genetic mutations can increase in frequency in a population quite rapidly, even if the fitness advantage to the organism is small.

Students will be able to

- describe how variation, selection, and time fuel the process of evolution; and
- manipulate and analyze data.

CURRICULUM CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	HS-LS1-1, HS-LS2-1, HS-LS2-2, HS-LS2-6, HS-LS2-7, HS-LS3-1, HS-LS3-3, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5 HS.LS1.A, HS.LS2.C, HS.LS4.B, HS.LS4.C
Common Core (2010)	CCSS.ELA-Literacy.RST.9-10.3, CCSS.ELA-Literacy.RST.9-10.4, CCSS.ELA-Literacy.RST.9-10.7 CCSS.Math.Practice.MP.2, CCSS.Math.Practice.MP.3, CCSS.Math.Practice.MP.4, CCSS.Math.Practice.MP.5
AP Biology (2012–13)	1.A.1, 1.A.2, 1.A.4, 1.C.3, 4.C.3
IB Biology (2016)	3.1, 5.1, 5.2, 10.3

KEY TERMS

adaptation, allele, allele frequency, Hardy-Weinberg, melanism, mutation, natural selection, variation

TIME REQUIREMENTS

This lesson was designed to be completed within one or two 50-minute class periods.

SUGGESTED AUDIENCE

This lesson is appropriate for high school biology (all levels including AP and IB) and introductory college biology.

PRIOR KNOWLEDGE

Students should have a basic understanding of evolution, adaptation, and algebra.

MATERIALS

calculator

computer and the Selection Coefficient spreadsheet file found under the "Survival of the Fittest—Battling Beetles" activity at <http://www.hhmi.org/biointeractive/classroom-activities-battling-beetles>.

The Making of the Fittest: Natural Selection and Adaptation

TEACHING TIPS

- Fill a few plastic sandwich bags with 15 grams of paper clips and pass them around so that students have an idea of how much a rock pocket mouse weighs.
- You may want to show the film more than once so students can take notes. Encourage them to write down questions they have about the film's content.
- Students should understand that individuals do not evolve but that populations evolve and that variations may be favorable, neutral, or negative. Variations occur randomly and not "as needed."
- Explain that the Hardy-Weinberg theorem describes conditions under which evolution will *not* occur. This informs us about the conditions under which it *will* occur, such as small population size, migration, nonrandom mating, occurrence of mutation, and, finally, selection. Selection is influenced by factors such as environmental change, predation, and disease. These actively influence the competitive advantage of specific traits present in a population. Point out that a population will almost always meet one or more of these conditions. In other words, populations are always evolving.
- Reinforce with students that dominant alleles are not always more common. The allele for dark-colored fur in rock pocket mice is dominant, but it is only common in populations living on dark substrates.
- If your students are not comfortable with the math involved in solving the Hardy-Weinberg questions, it may be helpful to go over the problems in Part 1 as a class. We provide the stepped-out math in the answer key for Part 1.
- We provide information about how to mathematically derive the selection coefficient in the "Survival of the Fittest—Battling Beetles" activity located at <http://www.hhmi.org/biointeractive/classroom-activities-battling-beetles>. The spreadsheet is also at that location.
- Part 3 requires access to a computer. You may want to assign this part as homework and e-mail the spreadsheet file to your students.

ANSWER KEY

QUESTIONS TO ANSWER WHILE WATCHING THE FILM

1. Watch the short film *The Making of the Fittest: Natural Selection and Adaptation*. As you watch, record the following information.

- a. What specific trait did researchers study in this investigation? **Fur color, specifically melanism, is the trait they studied.**
- b. How does this trait affect the survival of the mice in different environments?

Depending on the color of the substrate, fur color may or may not help rock pocket mice blend in with their environment. On a light-colored substrate, mice with fur that is light in color are camouflaged and are not very obvious to predators. On a dark substrate, mice with dark-colored fur blend in and are better able to avoid predation. Predators readily spot mice with light-colored fur. Mice that survive predation are more likely to live, reproduce, and pass on their favorable trait for fur color.

c. What is the genetic basis of the trait? **Mutations in the *Mc1r* gene are responsible for the appearance of dark fur color in this particular population of rock pocket mice. (Note: Mutations of other genes in the pigment pathway may play a role in other mouse populations. See the lesson "The Biochemistry and Cell Signaling Pathway of the *Mc1r* Gene" for more information.)**

PART 1: REVIEWING THE PRINCIPLES OF THE HARDY-WEINBERG THEOREM

1. If there are 12 rock pocket mice with dark-colored fur and 4 with light-colored fur in a population, what is the value of q ? Remember that light-colored fur is recessive. **$q = 0.5$**

Explanation: $q^2 = (4/16)$, or 0.25 ; therefore, $q = \sqrt{0.25}$, or 0.5

2. If the frequency of p in a population is 60% (0.6), what is the frequency of q ? **$q = .4$**

Explanation: If the frequency of p in a population is .6 then the frequency of q is .4 since $p + q = 1$.

3. In a population of 1,000 rock pocket mice, 360 have dark-colored fur. The others have light-colored fur. If the population is at Hardy-Weinberg equilibrium, what percentage of mice in the population are homozygous dominant, dark-colored mice?

The Making of the Fittest: Natural Selection and Adaptation

$$p^2 = 0.04, \text{ or } 4\%$$

Explanation: $q^2 = 640/1,000 = 0.64$, so, $q = 0.8$; because $p + q = 1$, $p = 0.2$ and $p^2 = (0.2)(0.2) = 0.04$

PART 2: APPLYING HARDY-WEINBERG TO POCKET MOUSE FIELD DATA

1. Calculate the overall frequencies of light-colored mice and dark-colored mice caught on light-colored substrates.

frequency = number of mice of one color/total number of mice

Frequency of light-colored mice = $120/168 = 71\%$; Frequency of dark-colored mice = $48/168 = 29\%$

2. Calculate the overall frequencies of light-colored mice and dark-colored mice caught on dark-colored substrates.

frequency = number of mice of one color/total number of mice

Frequency of light-colored mice = $3/57 = 5\%$; Frequency of dark-colored mice = $54/57 = 95\%$

3. Using the Hardy-Weinberg equation and data from the table above, determine the number of mice with the DD and Dd genotypes on the light, rocky, granite substrate.

Frequency of mice with the dd genotype on light-colored substrate = 71%

Frequency of mice with the DD genotype on light-colored substrate = 3%

Frequency of mice with the Dd genotype on light-colored substrate = 26%

4. Using the Hardy-Weinberg equation and data from the table above, determine the number of mice with the DD and Dd genotypes on the dark, rocky lava substrate.

Frequency of mice with the dd genotype on dark-colored substrate = 5%

Frequency of mice with the DD genotype on dark-colored substrate = 61%

Frequency of mice with the Dd genotype on dark-colored substrate = 34%

5. Which fur color seems to have the greatest overall selective advantage? Use data collected from both dark-colored and light-colored substrates to support your answer.

Dark fur color seems to have the greatest selective advantage. On the light-colored substrate, 29% of the mice have dark fur, while only 5% of the mice on the dark-colored substrate have light fur. Also, at collecting site no. 6, where there is a light-colored, rocky substrate, 43 out of 77 mice collected had dark-colored fur—over half of the sampled population. Dark-colored fur seems to have a selective advantage over light fur color.

6. According to the film, what environmental change gave a selective advantage for one coat color over another?

The color of the landscape changed so that some members of the population were more visible to predators than other members were. That is what happened in the film. When sections of the landscape became dark, the light-colored mice were at a selective disadvantage.

7. In a separate study, 76 rock pocket mice were collected from four different, widely separated areas of dark lava rock. One collecting site was in Arizona. The other three were in New Mexico. Dr. Nachman and colleagues observed no significant differences in the color of the rocks in the four locations sampled. However, the dark-colored mice from the three New Mexico locations were slightly darker than the dark-colored mice from the Arizona population. The entire Mc1r gene was sequenced in all 76 of the mice collected.

The mutations responsible for the dark fur color in the Arizona mice were absent from the three different populations of New Mexico mice. No Mc1r mutations were associated with dark fur color in the New Mexico populations. These findings suggest that adaptive dark coloration has occurred at least twice in the rock pocket mouse and that these similar phenotypic changes have different genetic bases. How does this study support the concept that natural selection is not random?

Evidence that natural selection is not random is the fact that when different genetic mutations produce the same phenotypic results in different areas, these similar adaptations are favored under similar conditions. An example provided in the film is the different populations of rock pocket mice with mutations that result in dark fur color.



*The Making of the Fittest:
Natural Selection and Adaptation*

LESSON
TEACHER MATERIALS

Dr. Carroll summed it up in the statement: “Evolution can and does repeats itself.” This is evidence that natural selection is not random.

8. To determine if the rock pocket mouse population is evolving, explain why it is necessary to collect fur color frequency data over a period of many years.

The data collected represent only one moment in time. If the population is evolving, the frequency of the two alleles for fur color will change over time. If the population is not under selective pressure, or is not evolving, the frequencies will remain approximately the same.

PART 3: HARDY-WEINBERG EXTENDED

1. Use the spreadsheet to determine how the selection coefficient (s) influences the phenotype of future generations. Substitute increasingly large numbers for s . Record each new value and describe what happens to the frequencies of p and q over the next five generations.

When the value of s increases, the value of p increases while the value of q decreases in each generation. Students should record the values of s and either record or print the values for p and q . During this exercise, the frequency of the dominant phenotype increases as the frequency of the recessive phenotype decreases.

2. Explain how the selection coefficient and natural selection are related. **The selection coefficient is a numerical representation of how much advantage or disadvantage a particular variation or trait provides an organism. It provides a way to mathematically model and predict evolutionary change.**

3. In areas with primarily dark-colored substrate, dark-colored mice have a selective advantage over light-colored mice. Therefore, mice with one or more copies of the dominant $Mc1r D$ allele have a selective advantage over mice with two copies of the $Mc1r d$ allele.

In the film, Dr. Carroll says that with a 1% selection advantage, it takes 1,000 years for 95% of the mice to have the dominant phenotype. With a 10% selection advantage, it would take just 100 years. Use the spreadsheet to verify these facts.

a. Find out how many generations following the first appearance of a dark-colored mutation it would take for 95% of the mice to express the dominant dark-colored phenotype given a 1% advantage ($s = 0.01$). Rock pocket mice have approximately one litter of pups a year, so the number of generations will be equal to the number of years. You will not be able to use the graph on the Main Page tab since it only goes up to 100 generations. So, you will need to look at column D of the worksheet called Main Worksheet. Scroll down until the value is greater than 0.95. Record your answer below.

It would take about 936 generations for 95% of the mice to express the dominant dark-colored phenotype.

b. Repeat the process for a 10% advantage ($s = 0.1$).

It would take about 100 generations.

c. What would the selection coefficient need to be for 95% of the mice to have the dominant phenotype in just 50 years? Record your answer below.

The coefficient would need to be about 0.22, a 22% advantage.

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FIELD TESTERS

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