IN-DEPTH FILM GUIDE

DESCRIPTION

Evolution is happening right now, everywhere around us, and adaptive changes can sweep through a population in an evolutionary eyeblink. Dr. Michael Nachman, working in the field and lab, has quantified predation on rock pocket mice and identified adaptive changes in coat-color genes that allow the mice to travel under the radar of hungry predators.

KEY CONCEPTS

A. A mutation is a random change to an organism's DNA sequence.

B. The environment contributes to determining whether a mutation is advantageous, deleterious, or neutral.

C. Mutations that increase the fitness of an organism increase in frequency in a population.

D. Evolution can happen quickly (in 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.

E. Different mutations in the same gene, or even mutations in different genes, can result in the same phenotype.

F. While mutations can be random, natural selection is not random.

G. Selective pressure depends on the environment in which an organism lives. This means that other organisms in the environment (in this case, the predators) can be a selective force.

CURRICULUM AND TEXTBOOK CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	MS.LS2.A, MS.LS2.C, MS.LS3.A, MS.LS3.B, MS.LS4.B, MS.LS4.C HS.LS1.A, HS.LS2.A, HS.LS2.C, HS.LS3.A, HS.LS3.B, HS.LS4.B, HS.LS4.C
AP Biology (2012–13)	1.A.1, 1.A.2, 1.C.3, 3.C.1, 3.C.2
IB Biology (2009)	4.1, 5.4, D2
APES: Themes and Topics (2013)	**Themes:** 1, 3 **Topics:** II.A, II.C

Textbook	Chapter Sections
Miller and Levine, *Biology* (2010 ed.)	13.3, 16.3, 16.4, 17.1, 17.2
Reese et al., *Campbell Biology* (9th ed.)	1.2, 17.5, 22.2, 22.3, 23.1, 23.3, 23.4
Cunningham, *Environmental Science: A Global Concern* (11th ed.)	4.1, 4.2
Friedland, Relyea, and Courard-Hauri, *Environmental Science for AP** (2012 ed.)	Chapter 5

PRIOR KNOWLEDGE

Students should

- have a basic understanding of natural selection, evolution, and adaptation;
- have a basic understanding of what a food web is and that organisms fill specific niches in their environments;
- know what a gene is and that genes can code for proteins that determine traits; and
- know that genes and the traits they produce are inherited and that some traits provide organisms with a greater chance to survive and reproduce.

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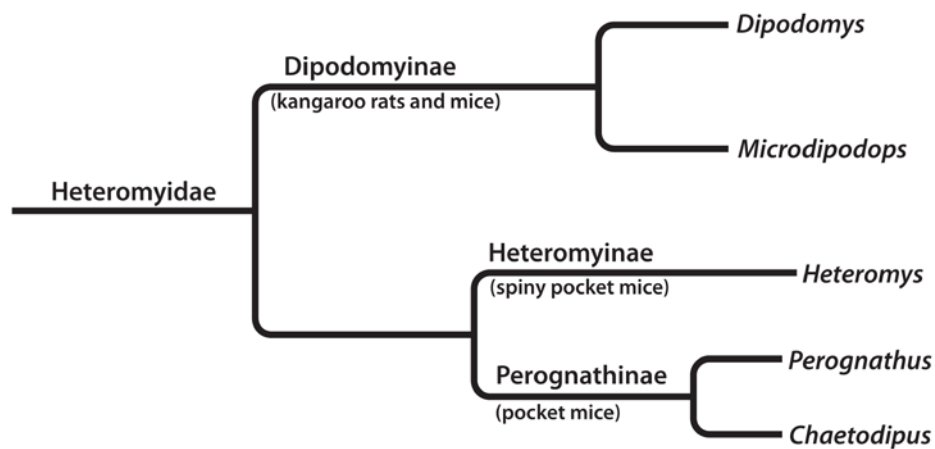**Page 1 of 9**

PAUSE POINTS

The film may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content description	Review Questions	Standards
1	0:00	3:14	• Pocket mice live in different environments in New Mexico's desert: lighter sands and darker lava rock. • Mice in the darker environment have darker fur on the top of their bodies, providing camouflage so predators won't see them. The mice's underbellies are white because there's so selective pressure for it to be dark; the predators come from above. • The differences in mouse fur color are driven by natural selection.	• Why do the pocket mice in the dark lava environment have white underbellies? • What drives the differences in mouse fur color?	NGSS (April 2013) MS.LS2.A, MS.LS2.C, HS.LS2.A, HS.LS2.C AP Biology (2012–13) 1.C.3, 4.B.3 IB Biology (2009) 5.1
2	3:15	5:20	• Gene mutations cause the darker mice. A mutation is a random change to an organism's DNA sequence. • Mutations are favored, rejected, or neutral depending upon an organism's environment. • Mutations in the Mc1r gene, which controls the amount of dark pigment in a mouse's hair follicles, cause the mouse to grow dark fur.	• How does a dark mouse appear in a population of light mice? • What is a mutation? • Are mutations bad? • What does the Mc1R gene do?	NGSS (April 2013) MS.LS3.A, MS.LS3.B, HS.LS1.A, HS.LS3.A, HS.LS3.B AP Biology (2012–13) 3.C.1, 3.C.2 IB Biology (2009) 4.1
	5:21	7:17	• In dark environments, the dark colored mice have an advantage; they survive better and have more offspring. • Evolution can happen quickly. A small advantage can lead to change in the population very quickly. • Mutations that increase the fitness of an organism increase in frequency in a population.	• How do you get a population of dark colored mice?	NGSS (April 2013) MS.LS4.B, MS.LS4.C, HS.LS4.B, HS.LS4.C AP Biology (2012–13) 1.A.1, 1.A.2, 1.C.3 IB Biology (2009) 5.4, D2
	7:18	10:29	• Evolution is not a random process. Mutations are random, but natural selection is not random. • Different mutations can cause the same phenotype. Evolution repeats itself in different environments.	• Did the mice on each of the dark lava flows have the same mutation? • Is evolution a random process?	NGSS (April 2013) MS.LS4.B, MS.LS4.C, HS.LS4.B, HS.LS4.C AP Biology (2012–13) 1.A.1, 1.A.2, 1.C.3 IB Biology (2009) 5.4, D2

BACKGROUND

The rock pocket mouse (*Chaetodipus intermedius*) is a small rodent in the Heteromyidae family. Even though it looks very much like a mouse, pocket mice are more closely related to pocket gophers than to true mice. We show the classification and Heteromyidae phylogeny below:

Kingdom: Animalia

Phylum: Chordata

Class: Mammalia

Order: Rodentia

Family   Heteromyidae

Subfamily: Perognathinae

Genus and species: *Chaetodipus intermedius*

Rock pocket mice, found throughout the southwestern United States, are well adapted to their dry, rocky, desert environment. Their kidneys highly concentrate waste, resulting in very viscous urine. They stay in cool underground burrows during the day. They have been observed plugging the entrance to their burrows, which may serve to retain moisture. When the temperature is extremely high, rock pocket mice may estivate, a form of dormancy characterized by lowered activity and metabolic rate.

Rock pocket mice are solitary and claim small territories. Females usually give birth to multiple litters of one to seven pups each year during the spring and summer months. Young have been seen emerging from their burrows from April through August.

The rock pocket mouse is an excellent model organism for studying geographic variation in phenotype within a single species. Rock pocket mice that live in areas with a light-colored granite substrate are usually sandy in color. Most rock pocket mice that live in areas covered by dark-colored lava rocks, however, are dark. Dark-colored rock pocket mice have uniformly pigmented hairs. Light-colored rock pocket mice have fur composed of banded hairs that have a dark-colored base and tip. Biologists have investigated and found the genetic mutations responsible for the dark-color mutation. Interestingly, different populations have different mutations that result in the same general dark-colored phenotype. Similar mutations are also responsible for dark-colored phenotypes in other species such as jaguars.

DISCUSSION POINTS

- In the short film *The Making of the Fittest: Natural Selection and Adaptation* (http://www.hhmi.org/biointeractive/making-fittest-natural-selection-and-adaptation), we learn that the dark-colored rock pocket mice have light-colored underbellies. Help students understand that the underside color of the rock pocket mouse would not be under strong selection pressure since it is not involved in camouflage. It is likely that there has been a mutation for dark-colored underbellies, but without selection for the trait, it has not become common.

- Your students may wonder why camouflage is important for a nocturnal species such as the rock pocket mouse. Nocturnal predators such as owls are able to discern color differences at night. In the 1940s, Dr. Lee Dice conducted experiments showing this. See the paper by Dr. Dice in the references below for more information.

- It seems that dark coloration lends some selective advantage even on a light-colored substrate. Ask your students if they can come up with a good explanation. Researchers think it is because rocks and shrubs cast shadows, and the dark-colored mice are pretty well hidden unless they run across the open, light-colored, sandy areas. The same cannot be said of light-colored mice on dark-colored substrates; they stand out whether or not they are in shadow.

- Be sure to reemphasize with your class that mutation is random. The dark coloration in the rock pocket mouse did not arise because there was a lava flow. Rather, a random mutation proved adaptive to the mice living in areas of dark-colored volcanic rock. Because dark coloration was helpful in this environment, more mice with the dark-color mutation survived to reproduce, thus passing on their genes (including the mutation for dark-colored fur) to the next generation with greater frequency than those without the mutation. In a population of mice living in areas of light-colored rock, the mutation would not be adaptive and would therefore not persist.

- The rock pocket mouse story is very similar to another that your students may have heard about, that of the peppered moths. The peppered moth can be light colored or dark colored. Dark-colored peppered moths became more common in Britain following the Industrial Revolution, in part because they were able to avoid predation by blending in with soot-covered trees when resting. You or your students may have heard that this story is "fake," and, indeed, there were some problems with the original research. The essential elements are, however, correct and a good example of natural selection "in action." For more on the peppered moths and the problems cited by some, see Ken Miller, "The Peppered Moth—an Update," Evolution Resources, August 1999, www.millerandlevine.com/km/evol/Moths/moths.html.

CLASSROOM RESOURCES FOR THE FILM

Color Variation over Time in Rock Pocket Mouse Populations (www.biointeractive.org/color-variation-over-time-rock-pocket-mouse-populations**)**

A data collection and analysis lesson that examines selection for coat color in rock pocket mouse populations on different-colored substrates over time. Students collect data, prepare graphs, and answer questions that apply the concepts introduced in the film.

Appropriate for middle school life science, high school biology (all levels including AP and IB)

Allele and Phenotype Frequencies in Rock Pocket Mouse Populations (www.biointeractive.org/allele-and-phenotype-frequencies-rock-pocket-mouse-populations**)**

A lesson that uses real rock pocket mouse data collected by Dr. Michael Nachman and his colleagues to illustrate the Hardy-Weinberg principle. Students use the data to calculate allele and phenotype frequencies and then manipulate selection values using a spreadsheet.

Appropriate for high school biology (all levels including AP and IB), introductory college biology

Molecular Genetics of Color Mutations in Rock Pocket Mice (www.biointeractive.org/molecular-genetics-color-mutations-rock-pocket-mice**)**

A lesson that requires students to transcribe and translate portions of the wild-type and mutant rock pocket mouse *Mc1r* genes and compare sequences to identify the locations and types of mutations responsible for the coat-color variation described in the film.

Appropriate for high school biology (all levels including AP and IB), introductory college biology

The Biochemistry and Cell Signaling Pathway of the *Mc1r* Gene (www.biointeractive.org/biochemistry-and-cell-signaling-pathway-mc1r-gene**)**

An advanced lesson that requires students to analyze partial DNA sequences of the *Mc1r* gene and identify the effects of altered amino acid chemistry on the functionality of the mutated MC1R protein pathway.

Appropriate for high school biology (all levels including AP and IB), introductory college biology

Natural Selection and Evolution of Rock Pocket Mouse Populations (www.biointeractive.org/natural-selection-and-evolution-rock-pocket-mouse-populations**)**

A lesson in which students analyze amino acid data and draw conclusions about the evolution of coat-color phenotypes in different rock pocket mouse populations. The lesson reviews the key concepts and causes of evolution, including mutation, gene flow, genetic drift, and natural selection.

Appropriate for high school biology (all levels including AP and IB), introductory college biology

OTHER BIOINTERACTIVE RESOURCES

Natural and Artificial Selection (www.biointeractive.org/natural-and-artificial-selection)

In this Click and Learn activity, students learn about natural and artificial selection. It features multiple clips from lectures on evolution (see below).

Endless Forms Most Beautiful, by Dr. Sean B. Carroll (media.hhmi.org/hl/05Lect1.html)

In this lecture, Dr. Carroll, a leader in the field of evolutionary developmental biology (or evo devo), explores how key developmental genes, natural selection, and time fuel the evolutionary process.

Evolution: Fossils, Genes, and Mousetraps, by Dr. Ken Miller (media.hhmi.org/hl/06Miller.html)

In this lecture, leading evolution educator Dr. Ken Miller discusses the controversy surrounding the teaching of evolution and presents compelling evidence for evolution and reasons why intelligent design is not scientific. The presentation features Dr. Miller's responses to questions from a live audience of high school students.

Stickleback Environment (www.biointeractive.org/stickleback-environment)

This video shows how, at the end of the Ice Age, the retreating ice sheet created many new lakes, some of which were colonized by stickleback fish. The presence of different predators in different lakes dictated the subsequent evolution of each isolated lake's stickleback population over the course of about 10,000 years. Some groups kept their spines to use against predatory fish, such as trout. Others lost their spines, perhaps to evade aquatic insect predators.

Fossil Record of Stickleback Evolution (www.biointeractive.org/fossil-record-stickleback-evolution)

This animation illustrates how a quarry site in Nevada carries the evolutionary history of a population of stickleback fish that resided there when it was a freshwater lake. In a short time span in evolutionary terms—about 10,000 years—we can see the size of the pelvic spines dramatically reduce in the fish population. This particular fossil record is remarkably complete with nearly year-by-year detail, which includes documentation of intermediate forms.

QUIZ QUESTIONS AND ANSWERS

The student version of this quiz is available as a separate file. We note the key concepts covered by each question here. You may wish to use some or all of the questions below to test your students' knowledge, depending on the content you wish to emphasize.

1. (Key Concept A) *Define "mutation."*
   A mutation is a change in an organism's DNA sequence. Students may also mention that the change is random, but this is not necessary for a complete answer.

2. (Key Concepts A, B, and F) *Is the following statement true or false? Justify your answer in one or two sentences: "Mutations are caused by selective pressure in the environment."*
   False; the mutations discussed in this film occurred at random. (Mutations can be nonrandom, but they are not caused by selective pressure.) Students may also mention that environmental selective pressure acts on the phenotype that results from the mutations but does not cause the mutations or the phenotype to appear.

3. (Key Concepts B and G) *Is the following statement true or false? Justify your answer in one or two sentences: "The same mutation could be advantageous in some environments but deleterious in others."*
   True; the environment or selective pressure determines whether a mutation is beneficial.

4. (Key Concepts A, B, and F) *Is the following statement true or false? Justify your answer in one or two sentences: "The appearance of dark-colored volcanic rock caused the mutation for black fur to appear in the rock pocket mouse population."*
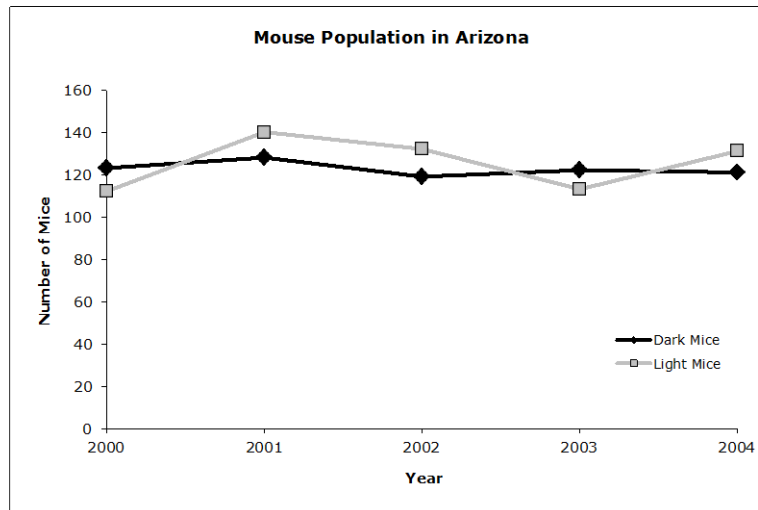   **False; selective pressure does not cause mutations but rather determines whether a mutation is advantageous or deleterious in a particular environment. Students may also mention that the dark-colored volcanic rock played a role in making dark-colored fur (and the corresponding alleles or mutations) favored, but this is not necessary for a complete answer.**

5. <u>(Key Concepts B, C, and G)</u> *Explain how the environment plays a role in changing the frequency of a mutant allele in a population.*

    Some traits are more advantageous (or deleterious) in certain environments than others. As a result, organisms with traits (and therefore the mutations that result in those traits) that make them better suited to a particular environment are more likely to have offspring and pass on their genes. Over time, this results in an increase in the frequency of mutations that encode beneficial traits for that environment (or, conversely, a decrease in the mutations that influence deleterious traits in that particular environment). Students may provide an example to support their answers (such as the rock pocket mice from the film), but this is not necessary for a complete answer.

6. <u>(Key Concepts C, D, and F)</u> *As you saw in the film, rock pocket mice evolved to have dark-colored fur in certain habitats. In three to five sentences, explain how this trait increased in frequency in the population. Include the following key terms: "fitness" (or "fit"), "survival" (or "survive"), "selection" (or "selective"), and "evolution" (or "evolve").*

    A complete answer should resemble the following, with partial credit given to students who do not include all the key terms or concepts (key terms are in *italics*): "Rock pocket mice with dark-colored fur were more *fit* on dark-colored volcanic rock because visual predators could not see them well; that is, natural *selection* favored individuals with dark-colored fur. As a result, more of the dark-colored mice *survived* and reproduced. This caused the population of rock pocket mice to *evolve* to have more individuals with dark-colored fur."

7. <u>(Key Concept F)</u> *Near the end of the film, Dr. Sean B. Carroll states that "while mutation is random, natural selection is not." In your own words, explain how this is possible.*

    A complete answer for this question should include the idea that natural selection acts on traits, which results in the mutations for those traits being more likely to be passed on to the next generation. However, it does not actually cause the mutations to appear in the population; many mutations appear randomly. Paraphrasing the above quote is not sufficient for a complete answer.

8. <u>(Key Concepts D and E)</u> *Suppose you are studying a recently discovered population of rock pocket mice with dark-colored fur that lives on volcanic rock. You take a DNA sample from a member of this new population and determine the DNA sequence of a gene known to play a role in fur color. The sequence you get is identical to that of the same gene in another rock pocket mouse population with dark-colored fur that lives on a different patch of volcanic rock. Which of the following could explain this observation?* [Answer is in **bold**.]
    a. The mice in the two populations evolved from the same ancestral population.
    b. The volcanic rock caused the same mutation in each rock pocket mouse population, resulting in dark coloration.
    c. The same mutation spontaneously arose in the two different populations.
    d. **Both (a) and (c) are possible.**
    e. All of the above are possible.

9. <u>(Key Concept G)</u> *For rock pocket mice, which of the following contributes to selective pressure favoring dark-colored fur? Write "yes" or "no" next to each of the four possible responses.* ***There may be more than one yes response.***

Predators	**Yes**	Genetic mutations	**No**
Rock color	**Yes**	Availability of food for the rock pocket mice	**No**

10. <u>(All Key Concepts)</u> *Suppose you are studying a new population of rock pocket mice in Arizona. These mice live on a recently discovered patch of dark-colored volcanic rock. This environment does not have nearly as many visual predators as in previously studied areas in New Mexico. You observed the following numbers of light- and dark-colored mice on this new patch of rock.*
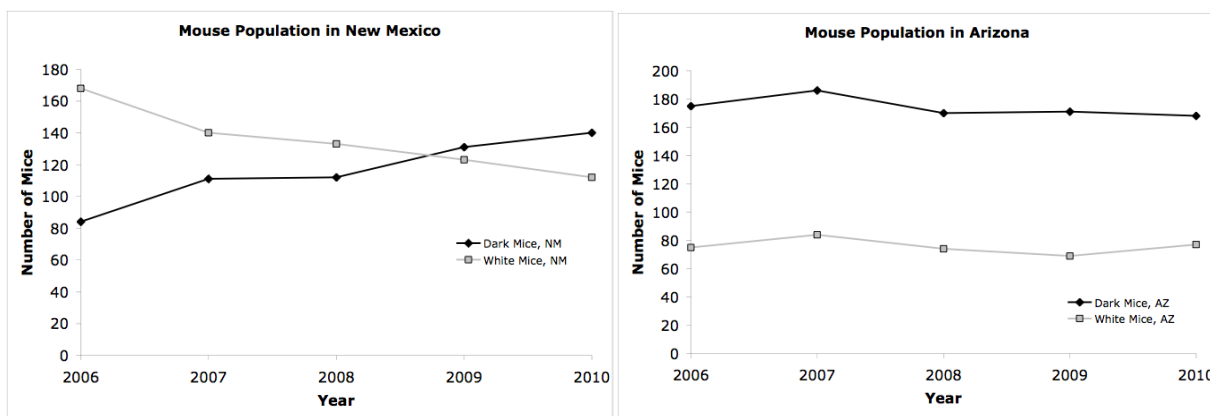

a. *In one or two sentences, summarize the data presented in the graph.*
   Students should note that the numbers of both light- and dark-colored mice are relatively stable over the observed time period.

b. *Provide one possible hypothesis that would explain the observed data. Be sure to include the following key words in your answer: "selection" (or "selective"), "fitness" (or "fit"), and "survival" (or "survive").*
   Sample answer (key terms are in *italics*): "Due to the absence of predation pressure, having light- or dark-colored fur does not make a difference to an organism's overall *fitness* and therefore likelihood of *survival*. The two coat colors are equally suited to the environment, so natural *selection* does not change the frequency of these traits."

   You next decide to move 50 of these newly discovered light-colored rock pocket mice from Arizona to a colony in New Mexico that also lives on dark-colored volcanic rock. You also move 50 dark-colored mice from the New Mexico colony to the Arizona colony. You monitor the populations for five years and observe the following.

Mouse Population in New Mexico — **Mouse Population in Arizona**

c. In one or two sentences, summarize the data presented in the graphs above.
The population of dark-colored mice in New Mexico is increasing while the population of light-colored mice is decreasing. In Arizona, there is little to no change in the light- and dark-colored mouse populations.

d. Provide an explanation for these observations. Be sure to include the following key words in your answer: "selection" (or "selective"), "fitness" (or "fit"), and "survival" (or "survive").
Sample answer (key terms are in *italics*): "In New Mexico, there is a *selective* advantage to having dark-colored fur. Dark-colored mice are less visible to predators. This makes them more *fit* in this environment and therefore more likely to *survive* and reproduce. In Arizona, where there are fewer visual predators, there is no selective advantage to light- or dark-colored fur. Different colored mice are equally fit and therefore equally likely to survive and reproduce."

Before your experiment above, you take a DNA sample from one dark-colored mouse in each population and sequence a gene known to play a role in making mice dark colored. You discover that the dark-colored mice from Arizona have a different allele of this gene than the dark-colored mice from New Mexico.

e. Design an experiment to test which population of dark-colored mice is more evolutionarily fit in an environment of your choice. You may want to use the above experiments as a guide. Be sure to state your hypothesis, as well as what type of data you will record.
Because this question is very open ended, a wide range of creative answers is possible. Important points to be included in any answer for full credit are
- **a clearly stated hypothesis;**
- **an experimental design that tests the stated hypothesis; and**
- **a description of data that the students would collect in their experiments, which must be able to test the stated hypothesis.**

Possible complete response: "I hypothesize that the population of dark-colored mice from Arizona is more evolutionarily fit than the population of dark-colored mice from New Mexico in a desert with black sand. To test this hypothesis, I will take 50 dark-colored mice from each population and place them in a black sand desert. Each population will be on a separate patch of black sand that is identical in every way, but I will keep them separate to prevent interbreeding. Every year for five years, I will count the number

of mice in each patch of black sand and see how many mice from each population survive. If more of the mice from Arizona survive than mice from New Mexico, this will support my hypothesis."

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