What Causes Different Fur Colors?

hhmi | BioInteractive

Activity
Educator Materials

OVERVIEW

This inquiry-based activity is based on content covered in the short film *The Making of the Fittest: Natural Selection and Adaptation*. Instead of front-loading information from the film, the activity guides students through "figuring out" the key concepts first, including how a genotype produces a particular phenotype and how natural selection influences phenotypes in a population.

In Part 1, students observe, ask questions, and make predictions about rock pocket mice with different fur colors in different environments. In Part 2, they learn about the *Mc1r* gene, which encodes a protein called MC1R that plays an important role in fur color. Students transcribe and translate a segment of *Mc1r* in mice with different fur colors, then identify variations. In Parts 3 and 4, they explain how a change in an amino acid sequence affects the function of the MC1R protein, and how that change might affect fur color and the survival of mice in different populations.

Additional information related to pedagogy and implementation can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- A variation, or mutation, in an organism's DNA sequence may affect the expression of the gene product. Both the type of variation and its location in the gene determine whether it will affect the gene product and the organism's phenotype.
- A DNA molecule has two strands: a coding strand and a template strand. The cell transcribes the template strand into messenger RNA (mRNA) and then translates the mRNA into amino acids.
- Variations that increase the ability of an organism to survive and reproduce are more likely to be passed on due to natural selection.
- The environment contributes to determining whether a variation is important to species survival.

STUDENT LEARNING TARGETS

- Make observations about a phenomenon and generate questions about it.
- Based on the sequence of the coding strand of DNA, determine the sequence of the template strand, the mRNA, and the protein.
- Identify differences among DNA sequences and among amino acid sequences.
- Explain the relationship between variations in a DNA sequence and variations in phenotype.
- Explain the relationship between natural selection and the frequency of genetic and phenotypic variations in a population.

PRIOR KNOWLEDGE

Students should be familiar with:

- inheritance (i.e., offspring inherit genes from their biological parents)
- basic molecular biology, including transcription and translation (a schematic is provided in Part 2)
- that a protein's amino acid sequence determines its structure, which determines its function (students may also be able to develop this understanding as a result of completing this activity)

MATERIALS

- copies of the "Student Handout"
- the "DNA Evidence Sheet"
- the "Genetic Code Chart"
- access to the short film *The Making of the Fittest: Natural Selection and Adaptation*

TEACHING TIPS

- Distribute each part of the "Student Handout" separately. Students should receive the next part only after they have completed each previous part. It is not recommended to give students all parts of the handout at once.
- Students may work on the handout individually or in small groups.
- To navigate from one part of the activity to the next, consider facilitating a whole-group discussion after students have had ample time to work. You may use this discussion to surface student ideas that they will be able to use to continue explaining the phenomenon.
- In **Part 1**, students need a colored version of Figure 1 in the "Student Handout." If color printing is limited or unavailable, you can project the figure in class or print a few color copies for students to share (which can be laminated for reuse). You can also download Figure 1 as a JPG file from this resource's webpage and distribute it to students digitally.
- In **Part 2**, students view the first 20 codons of the *Mc1r* DNA sequence for two mice (in the "DNA Evidence Sheet" handout). They are asked to transcribe and translate 16 of these codons (Tables 1 and 2 in the "Student Handout"). If this is too time-consuming or tedious for your students, consider having students first identify which codon differs between the two mice (Codon 18). Students can then fill in Tables 1 and 2 for that one codon only.
- In **Parts 3 and 4**, students view the film *The Making of the Fittest: Natural Selection and Adaptation*. Avoid showing the film or front-loading too much information before this point. Instead, allow students to engage in sensemaking and figure out the phenomenon first.
    - Consider having students complete some or all of the accompanying film activity while watching the film.
- In **Part 5**, students answer several analysis questions. To reduce the class time needed for this activity, students can do Part 5 individually as homework and/or as a formative assessment to gauge understanding.

ANSWER KEY

PART 1: How Are Rock Pocket Mouse Populations Different?

1. What do you notice about the four images in Figure 1?
   Students' answers will vary. They will likely observe the different fur colors in different environments.

2. What questions do you have about your observations of these images?
   Students' answers will vary. They may include questions about where the mice with different fur colors live and what determines different fur colors.

3. Predict how likely each mouse is to survive in the environment where they live.
   Students' answers will vary. Based on students' prior knowledge, they might include responses that focus on adaptation and/or selection.

4. What type(s) of data would help you explain why these mice have different fur colors?
   Preferred answers will include student ideas around genes, genetics, DNA, etc. If students struggle with getting to these ideas, consider using leading questions such as "What makes mice different colors?"

and/or "Why are mice born different colors?" This may also be an ideal opportunity to discuss misconceptions like phenotypes changing during an organism's lifetime.

PART 2: Are There Genetic Differences Between Mice with Different Fur Colors?

5. Preview Tables 1 and 2 on the next page. The first four columns of both tables have been filled out as examples.
   a. What patterns exist in the base pairings between the **coding strand** and the **template strand**? In other words, what "rules" could you use to get the template strand sequence from the coding strand sequence?
   Students should notice that A pairs with T and G pairs with C.
   b. What patterns exist in the base pairings between the **template strand** and the **mRNA**? In other words, what "rules" could you use to get the mRNA sequence from the template strand sequence?
   Students should notice that A pairs with U and G pairs with C.
6. Complete the rest of Tables 1 and 2, or whichever parts are indicated by your instructor…
   Completed versions of Tables 1 and 2 are shown at the end of this document.
7. Use Tables 1 and 2 to answer the following questions.
   a. Are there differences between the *Mc1r* gene sequences (first 20 codons) of these mice? If yes, which nucleotides in the DNA coding strands are different?
   Codon 18 is different (CGC in the light-colored mouse and TGC in the dark-colored mouse). Students may also say that a C changed to a T.
   b. Do any differences in the DNA sequences result in differences in the amino acid sequences? If yes, which amino acid(s) are different?
   Amino acid 18 is different (Arg in the light-colored mouse and Cys in the dark-colored mouse).
   c. How can changes in a DNA sequence lead to changes in an amino acid sequence?
   If a change in a DNA sequence results in a codon that "spells out" a different amino acid, it may change the amino acid sequence.

PART 3: Why Do Mice Have Different Fur Colors?

8. Figure 3 shows the first 20 amino acids for the MC1R protein in mice with **dark**-colored fur.
   a. Circle, or indicate in another way, the amino acid that differs between mice with dark-colored fur and mice with light-colored fur. What is this amino acid in mice with **light**-colored fur?
   Students should indicate the 18th amino acid in the sequence starting from the top (second-to-last amino acid from the end): Cys. In mice with light-colored fur, this amino acid is Arg instead.
   b. How could this amino acid difference result in mice with different fur colors?
   Students' answers will vary. They may say that if the protein has a different amino acid, it will have a different shape or function differently, which may cause the fur to look different.

PART 4: Do All Mice with a Certain Fur Color Have the Same Genetic Variations?

9. Complete Table 3 by filling in the missing amino acids. You can find the amino acid corresponding to each mRNA codon using the **"Genetic Code Chart"** from Part 2.
   A completed version of Table 3 is shown below.

Mouse fur color		**Light**	**Dark**	**Dark**	**Dark**	**Dark**
Location		**Pinacate** (desert)	**Pinacate** (lava flow)	**Kenzin** (lava flow)	**Armendaris** (lava flow)	**Carrizozo** (lava flow)
Codon 18	mRNA	CGC	UGC	CGC	CGC	CGC
	Amino acids	Arg	Cys	***Arg***	***Arg***	***Arg***
Codon 109	mRNA	CGG	UGG	CGC	CGG	CGG
	Amino acids	***Arg***	***Trp***	***Arg***	***Arg***	***Arg***
Codon 160	mRNA	CGG	UGG	CGG	CGG	CGG
	Amino acid	***Arg***	***Trp***	***Arg***	***Arg***	***Arg***
Codon 233	mRNA	CAA	CAC	CAA	CAA	CAA
	Amino acids	***Gln***	***His***	***Gln***	***Gln***	***Gln***

10. Answer the following questions using the data in Table 3.
    a. Based on these codons, how many versions of the MC1R protein are represented? At which codon(s) do their amino acids differ?
    Based on these codons, there are two versions of the protein: one for the dark-colored mice in Pinacate and one for all the other populations. These two versions differ at all four codons shown.
    b. Compare the amino acids of the mice with dark-colored fur to those of the mice with light-colored fur. What do you notice?
    For all four codons shown, the dark-colored mice from Pinacate have different amino acids from the light-colored mice. However, the dark-colored mice from the three other locations (Kenzin, Armendaris, and Carrizozo) have the same amino acids as the light-colored mice do, even though their fur color is different.

    You may want to tell students that these results suggest that* Mc1r *is not involved in fur color variation for the Kenzin, Armendaris, and Carrizozo populations. These populations may have dark-colored fur due to changes in genes other than* Mc1r *and probably evolved dark-colored fur independently of the Pinacate mice.
    c. Based on the information throughout this activity, why would variations in a trait like fur color be important to species survival?
    Variation in traits can be important for species survival when the environment changes. For rock pocket mice populations, for example, the environment can change from light-colored desert rocks to dark-colored lava rocks. Variations in fur color allow some mice in the populations to survive even under new conditions.

PART 5: How Can Changes in DNA Result in Changes in Populations?

11. In this activity, you identified specific changes in the *Mc1r* gene sequence that result in rock pocket mice with different fur colors. How might a particular version of the *Mc1r* gene become more or less common in a population over time?
    Students' answers should reflect an understanding of natural selection, which is discussed in the* Natural Selection and Adaptation *film. An example answer could be as follows:
    ***Mice with fur colors that "match" their environment have a survival advantage, because they are less likely to be seen and killed by visual predators. For example, mice with dark-colored fur have a survival advantage in an environment with dark-colored rocks. These mice are more likely to survive and reproduce, passing on* Mc1r *variations for dark-colored fur to their offspring. Thus, these variations become more common in the mouse population over time. Mice with light-colored fur in this same**

environment would be at a disadvantage, as they would be more likely to be seen and killed by predators. They are less likely to survive, reproduce, and pass on* Mc1r *variations for light-colored fur. So, these variations would become less common in the population over time.

12. Scientists have made these observations:
    - The mouse populations that live on **light**-colored desert rocks consist mainly of mice with **light**-colored fur (and a few mice with dark-colored fur).
    - The mouse populations that live on **dark**-colored volcanic rocks consist mainly of mice with **dark**-colored fur (and a few mice with light-colored fur).

    How do you explain these observations? Make sure to discuss why the populations have individuals with *both* fur colors in different numbers.
    Students should mention that variations occur at random during reproduction, so there are always variations among individuals in a population. Variations in a population make it more likely that some individuals will survive a major environmental change. Make sure to address any misconceptions that variations arise if and when organisms "need" them.

13. Describe another example where changes in DNA may have resulted in changes in appearance among different populations of the same species.
    Answers will vary depending on students' prior knowledge, including other examples you may have discussed in class. One example is variations in human traits, such as eye color or skin color.

REFERENCES

Hoekstra, Hopi E., and Michael W. Nachman. "Coat color variation in rock pocket mice (*Chaetodipus intermedius*): From genotype to phenotype." In *Mammalian Diversification: From Chromosomes to Phylogeography*, edited by Eileen A. Lacey and Philip Myers. University of California Press, 2006: 79–99. https://doi.org/10.1525/california/9780520098534.003.0003.

Nachman, Michael W., Hopi E. Hoekstra, and Susan L. D'Agostino. "The genetic basis of adaptive melanism in pocket mice." *Proceedings of the National Academy of Sciences* 100, 9 (2003): 5268–5273. https://doi.org/10.1073/pnas.0431157100.

CREDITS

Written by Jason Crean, Saint Xavier University, IL; Kristin Rademaker

Edited by Susan Dodge; Esther Shyu, Laura Bonetta, HHMI

Reviewed by Jessica Bean, University of California, Berkeley, CA

Image credits:

- Figure 1 by Michael Nachman, University of California, Berkeley, CA; Hopi Hoekstra, Harvard University, MA
- Figures 2 and 3 and images in the "DNA Evidence Sheet" and "Genetic Code Chart" by Heather McDonald

Table 1. *Mc1r* gene sequence in a mouse with light-colored fur.

Codon Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
DNA coding strand	ATG	CCC	ATG	CAG	***GAG***	***CCC***	***CAG***	***AGG***	***AGG***	***CTA***	***CTG***	***GGT***	***CCT***	***TTC***	***AAC***	***TCC***	***ACC***	***CGC***	***ACA***	***GGC***
DNA template strand	TAC	GGG	TAC	GTC	***CTC***	***GGG***	***GTC***	***TCC***	***TCC***	***GAT***	***GAC***	***CCA***	***GGA***	***AAG***	***TTG***	***AGG***	***TGG***	***GCG***	***TGT***	***CCG***
mRNA	AUG	CCC	AUG	CAG	***GAG***	***CCC***	***CAG***	***AGG***	***AGG***	***CUA***	***CUG***	***GGU***	***CCU***	***UUC***	***AAC***	***UCC***	***ACC***	***CGC***	***ACC***	***GGC***
Protein	Met	Pro	Met	Gln	***Glu***	***Pro***	***Gln***	***Arg***	***Arg***	***Leu***	***Leu***	***Gly***	***Pro***	***Phe***	***Asn***	***Ser***	***Thr***	***Arg***	***Thr***	***Gly***

Table 2. *Mc1r* gene sequence in a mouse with dark-colored fur.

Codon Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
DNA coding strand	ATG	CCC	ATG	CAG	***GAG***	***CCC***	***CAG***	***AGG***	***AGG***	***CTA***	***CTG***	***GGT***	***CCT***	***TTC***	***AAC***	***TCC***	***ACC***	***TGC***	***ACA***	***GGC***
DNA template strand	TAC	GGG	TAC	GTC	***CTC***	***GGG***	***GTC***	***TCC***	***TCC***	***GAT***	***GAC***	***CCA***	***GGA***	***AAG***	***TTG***	***AGG***	***TGG***	***ACG***	***TGT***	***CCG***
mRNA	AUG	CCC	AUG	CAG	***GAG***	***CCC***	***CAG***	***AGG***	***AGG***	***CUA***	***CUG***	***GGU***	***CCU***	***UUC***	***AAC***	***UCC***	***ACC***	***UGC***	***ACC***	***GGC***
Protein	Met	Pro	Met	Gln	***Glu***	***Pro***	***Gln***	***Arg***	***Arg***	***Leu***	***Leu***	***Gly***	***Pro***	***Phe***	***Asn***	***Ser***	***Thr***	***Cys***	***Thr***	***Gly***

Differences between the sequences are highlighted in yellow and underlined. As shown, the only difference is in Codon 18.