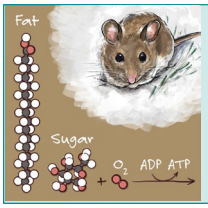

The Science of an Extreme Animal Athlete

hhmi | BioInteractive

Scientists at Work
Educator Materials

OVERVIEW

The Scientists at Work video *The Science of an Extreme Animal Athlete* follows a scientist who is studying the adaptations that allow deer mice living at high elevations to stay warm and active. The video shows how the inputs/outputs of cellular respiration may vary with elevation and explores why certain dietary macromolecules are useful in different environmental conditions. This video also reinforces the scientific method, including the importance of experimental controls.

The video is accompanied by two worksheets that guide students through different concepts in the film. Students should watch the entire video regardless of which worksheet they complete.

- In the **Metabolism worksheet**, students analyze the video through the lens of cellular respiration and metabolism, focusing on how metabolic fuel needs change in different environments.
- In the **Evolution worksheet**, students analyze the video through the lens of evolution by natural selection, focusing on how different populations within the same species have developed adaptations to survive and reproduce in their respective environments.

The educator document contains multiple resources for implementing this resource with students, including the following (select links to go directly to each section in the document):

- teaching tips for this resource
- suggested procedures for each worksheet
- assessment guidance, including sample answers, for questions in the Metabolism worksheet and the Evolution worksheet
- optional extensions for this resource

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

Metabolism worksheet

- The body uses food molecules to produce ATP (usable energy for cells) and release the heat needed to maintain body temperature.
- Two major types of food molecules, carbohydrates (sugars) and lipids (fats), can be used to produce ATP and heat through slightly different processes.
- The processes that produce ATP and heat are part of metabolism: the chemical reactions in the body that maintain life.

Evolution worksheet

- An adaptation is a characteristic that makes an organism more likely to survive and reproduce in its environment.
- Natural selection is a process by which heritable adaptations can become more common in a population over multiple generations.
- Hemoglobin is a protein that binds and transports oxygen to body tissues.

STUDENT LEARNING TARGETS

Metabolism worksheet

- Describe the reactants and products of carbohydrate (sugar) vs. lipid (fat) metabolism.
- Compare benefits and drawbacks of carbohydrate vs. lipid metabolism.

Evolution worksheet

- Describe how evolutionary adaptations enable populations of the same species to survive in different environments.
- Characterize the importance of hemoglobin for mammals and the benefits of certain hemoglobin adaptations (e.g., for highland deer mice).

PRIOR KNOWLEDGE

Metabolism worksheet

Students should have a basic understanding of:

- reading and interpreting chemical equations
- ATP and its contribution to body function
- how excess CO_2 is released from the body
- why scientists use controls to validate experimental results

Evolution worksheet

Students should have a basic understanding of:

- trait inheritance
- genetic variation

MATERIALS

- copies of the selected "Student Worksheet"
- access to the video *The Science of an Extreme Animal Athlete*

TEACHING TIPS

Implementing the Resource

- To increase accessibility for the video, you can:
  - Provide students with a copy of the video's transcript, which can be downloaded from this resource's webpage.
  - Turn on closed captioning, which is available on YouTube.
  - Use an audio descriptive version of the video if needed.
- Depending on your class goals, you may have students complete just the Metabolism worksheet, just the Evolution worksheet, or both.
  - If students are doing one worksheet more than one or two weeks after the other worksheet, it is recommended that they rewatch the video. While they may not need to retake notes, they should be encouraged to reread their notes from the first viewing and then supplement their notes during the second viewing.

Caveats and Clarifications

The video and worksheets simplify or omit certain terms. In particular:

- The terms "carbohydrate" and "sugar" are used interchangeably. In actuality, "sugar" is a term that includes multiple molecules (including glucose), all of which are carbohydrates. Starches and fibers are also carbohydrates.
- The term "fat" is used to mean "lipids," which are not explicitly referred to in the video. In actuality, fats are a type of lipid, along with waxes, steroids, oils, and phospholipids.
- The process of "cellular respiration" is described (e.g., in Figures 1 and 2 of the Metabolism worksheet) but not called out by name. You may want to introduce this term to students if you haven't already, or help students make the connection between cellular respiration in this resource and their prior learnings about cellular respiration.
- The terms "altitude" and "elevation" are used interchangeably. If you anticipate students being confused by this, you can provide a general differentiation between them: Elevation is a height that uses sea level as a reference level, whereas altitude's reference level can be either sea or ground level, depending on context.

Concepts to Reinforce/Common Misconceptions to Address

- The relationship between the terms "ATP," "energy," and "calories" tends to be difficult for students to comprehend and may require additional clarification.
  - A calorie is a unit of energy that is used to describe the energy contained in food.
  - ATP (adenosine triphosphate) is "usable energy" that drives biological processes (e.g., muscle contractions that facilitate movement, maintenance of body temperature, photosynthesis, DNA synthesis).
- The video uses the term "burning calories" in reference to both fats and carbohydrates. The word "burning" may cause students to incorrectly believe that calories are lost to the external environment. Clarify that the energy from those calories is not lost but transformed.
- Cellular respiration equations typically only show sugar/glucose as a reactant. However, other macromolecules can also be used. For example, Figures 1 and 2 in the Metabolism worksheet show different cellular respiration reactions. Figure 1 shows the "default" reaction with sugar, and Figure 2 shows another reaction with fat. Reviewing these figures with your class can be a valuable opportunity to reinforce the fact that carbohydrates are not the only energy source.
- Images of chemical reactions appear in both the video and the Metabolism worksheet. Students who are unfamiliar or struggle with interpreting chemical reactions may benefit from explicit instruction on the following:
  - **Reactants vs. products.** In chemical equations, reactants are always on the left side of the arrow, and products are always on the right side of the arrow.
  - **The number in front of a chemical formula.** Also called a coefficient, this number refers to the number of that molecule present in the reaction. Generally, these numbers are added to balance an equation; in this resource, the numbers are present so students can compare differences in oxygen requirement and carbon dioxide production between sugars and fats.
  - **The molecule(s) above the arrow.** ADP and ATP are shown above the arrows in the video and in Figures 1 and 2 of the Metabolism worksheet. In these cases, ADP (reactant) enters the reaction, gains a phosphate group, and is transformed into ATP (product). In other resources, the molecules above the arrow are typically catalysts or reagents rather than reactants and products.

Differentiation Techniques to Support Varying Learner Abilities

To provide students with additional support:

- Use sentence starters for open-ended questions. For example, the following sentence starter could be provided for Question 3 in the Evolution worksheet: "One adaptation I observed in the highland deer mouse is _____."

- Convert the worksheets into a process-oriented guided inquiry learning (POGIL)-style activity, where students work together to answer the questions. You can add "stop signs" after short sections to check in and correct misconceptions before students continue working.

To provide students with more challenge:

- Convert questions that provide additional scaffolding into open-ended questions. For example:
  - Remove the tables in Questions 3 and 4 of the Metabolism worksheet.
  - Remove the provided choices from multiple-choice questions, like Question 7 in the Metabolism worksheet.
- Have students work alone rather than in groups as suggested in the following "Procedure" section. Have students further investigate the topics in this resource using optional extensions.

PROCEDURE

The following procedure is just one way to implement this activity, specifically with a general biology classroom in mind. You should feel empowered to conduct this activity in a manner that is both responsive to your students as learners and supportive of your own teaching skills.

1. Introduce the video and review prior knowledge concepts if needed.
2. Indicate that students should record notes during the video, and provide instruction on how to do so. If there is a standard method for taking notes in your classroom, that would be ideal. Other methods include various types of guided notes (including Cornell notes and graphic organizers), and free-written notes.
3. Have students watch the video in whichever way is most suitable for your class format.
   - For hybrid/remote or 1:1 classes, students could watch individually on their own computers.
   - For in-person classes, students could watch the video together.
4. Have students compare notes with a partner. Encourage them to supplement their own notes based on discussion with their partner.
5. Lead a brief whole-class discussion to ensure comprehension of key concepts. Address any student misconceptions in the content areas of focus. You could also prepare slides or another type of presentation to facilitate this discussion.
6. Pass out your selected version of the "Student Worksheet." The "Overview" section describes each worksheet in more detail.
7. Separate students into groups of 2–4 to complete the worksheet together. Encourage them to use their notes and actively discuss each question.
   - The "Extension" in the Evolution worksheet can be assigned either as a regular part of the activity or as extra credit/optional. How you choose to use it with your students may depend on your class goals and student experience/comfort with reading primary literature.
8. Debrief key questions as a whole class. Which questions you deem "key questions" will depend on content areas of focus and/or questions that students were confused by or wanted more clarification on.

ASSESSMENT GUIDANCE

Most of the provided answers include more detail than would be provided by most students. They are meant to give additional information that you may want to discuss with students.

Metabolism Worksheet

1. The video discusses how a deer mouse's diet helps it survive. Like mice, humans also eat diets that contain carbohydrates (sugars) and fats.
   a. Carbohydrates, also called "carbs," include sugars, starches, and fibers. Give an example of a food with carbohydrates (for example, your favorite carbohydrate to eat if you have one).

Students can list any food with simple or complex carbohydrates — for example, candy or pasta. If a student identifies something that is not a carbohydrate, coach them toward the correct macromolecule type. This will help them better recall key differences between each type of macromolecule.

b. The "fats" mentioned in the video are examples of **lipids**: a group of molecules that includes fats, waxes, steroid hormones, and oils. Give an example of a food with lipids (for example, your favorite lipid to eat if you have one).
Students can list any food with lipids — for example, olive oil, avocado, peanut butter, or fish. If a student identifies something that is not a lipid, coach them toward the correct macromolecule type. This will help them better recall key differences between each type of macromolecule.

2. The video focuses on highland deer mice. If the scientists wanted to learn more about highland deer mice, why were they also collecting data from lowland deer mice?
Experiments typically have a control group with which to compare the experimental group. In this case, the lowland deer mice were the control group with which the scientists could compare the experimental group: the highland deer mice that they were asking questions about.

3. Identify the major differences between highland and lowland deer mice by filling out the following table:

<table>
<tr><th></th><th>Highland Deer Mice</th><th>Lowland Deer Mice</th></tr>
<tr><td>Environment
(Describe characteristics of the places where each population lives.)</td><td>• High elevations (i.e., mountaintops)
• Cold, windy, snowy
• Less oxygen available</td><td>• Lower elevations
• Warmer
• More oxygen available</td></tr>
<tr><td rowspan="2">Energy supply
(What type of "metabolic fuel" do they use more or less of?)</td><td>Use more fats</td><td>Use less fats</td></tr>
<tr><td colspan="2">*If students are identifying actual foods (e.g., acorns or grass) or are struggling to figure this out, you can mention that the question is asking for a macromolecule that one population "burns" more than the other.</td></tr>
<tr><td rowspan="2">Appearance
(What do they look like in the film?)</td><td>Student answers will vary depending on what they observe. They may say that both groups of mice look the same or that highland deer mice appear to have thicker, lighter-colored fur.</td><td>Student answers will vary depending on what they observe. They may say that both groups of mice look the same or that lowland deer mice appear to have thinner, darker-colored fur.</td></tr>
<tr><td colspan="2">*This question helps students practice making observations and drawing conclusions based on those observations. The differences that students observe in the video are not necessarily reflective of the scientifically established phenotypes of these mice. Although deer mice in some habitats do have different fur colors or lengths, fur differences between the highland and lowland deer mice have not yet been confirmed.</td></tr>
</table>

4. Identify the major differences between carbohydrates and fats by filling out the following table:

	Carbohydrates/Sugars	Fats
Activities that muscles use it for *(Describe one or two activities in each box to the right.)*	***High-intensity "burst" types of exercise, like sprinting***	***Lower-intensity or "submaximal" endurance activities, like marathons*** ***(Also shivering, though this is not discussed in the video)***
How long it takes to convert to usable energy *(Write either "quickly" or "longer" in each box to the right.)*	***Quickly***	***Longer***
How much usable energy is contained in 1 gram *(Write either "more" or "less" in each box to the right.)*	***Less***	***More***

5. Use Figures 1 and 2 to answer the following:
   a. Compare the processes in each figure by filling out the following table:

	Figure 1	Figure 2
Type of food molecule used	***Sugar***	***Fat***
Oxygen molecules (O_2) used *(Write a specific number in each box to the right.)*	***6***	***23***
Usable energy (ATP) produced *(Write either "more" or "less" in each box to the right.)*	***Less***	***More***
Heat produced *(Write either "more" or "less" in each box to the right.)*	***Less***	***More***

   b. What does a mammal's body do with the extra CO_2 produced by these processes? (Think about what happens to the CO_2 produced by your own body.)
   The body exhales/releases the extra CO_2 into the external environment.

   (Students who have studied the respiratory system may provide additional detail by tracing a molecule of CO_2 from the cell to the external environment. In humans, extra CO_2 diffuses out of the cell and into the circulatory system. A blood vessel transports the CO_2 to the lungs, where it is processed by various respiratory structures — alveoli, bronchioles, bronchi, trachea, and then mouth/nose — and finally released into the external environment from the mouth/nose.)

   c. Evaluate this statement: "Burning carbohydrates requires a lot more oxygen than burning fats." Based on the figures, explain why this statement may or may not be true.
   Students should explain why this statement is untrue. The following is a sample explanation:

This statement is not true based on Figures 1 and 2. Figure 2 shows that 23 oxygen molecules are required to burn fat. In contrast, Figure 1 shows that only 6 oxygen molecules are required to burn carbohydrates. So, burning carbohydrates requires less, not more, oxygen than burning fats.

(You may also want to address possible misconceptions around the word "burning" in this context, as noted in the misconceptions section.)

d. Which product(s) of the process in Figures 1 and 2 do you think highland deer mice need to survive in their environments? Explain your reasoning.
Students should point out at least one of the following products. A sample explanation is provided for each:
- ***Heat: Highland deer mice live in cold and snowy environments, so they need more heat to maintain their body temperatures.***
- ***ATP or "usable energy": Since highland deer mice don't hibernate, they need usable energy (in the form of ATP) for their daily activities (e.g., finding food or shelter or reproducing) throughout the year.***

6. If sugars can be used to produce ATP more quickly than fats can, why do the highland deer mice use more fats?
Although sugars can be used to produce ATP more quickly, fats can be used to produce more ATP and more heat — both of which help the highland deer mice survive in their cold mountaintop environment.

(You may also want to let students know that mammals store much more fat than carbohydrates, so fat can support sustained rates of heat and ATP production.)

7. Which of the following would a ratio of CO_2 to O_2 of 0.83 most likely indicate about a mouse's metabolism? (You may want to refer back to the video.)
   a. It was using mostly carbohydrates.
   b. It was using mostly fats.
   c. ***It was using a mixture of fats and carbohydrates.***
   d. It wasn't using fats or carbohydrates.

Evolution Worksheet

1. Hemoglobin is a protein that is critical to humans and other animals. Which of the following does hemoglobin carry to the tissues of the body?
   a. ***Oxygen (O_2)***

2. How does the hemoglobin in highland vs. lowland deer mice differ?
Compared to the hemoglobin in lowland deer mice, the hemoglobin in highland deer mice is better able to bind oxygen in the lungs, so it can transport more oxygen to the tissues.

3. Give **one** example of an adaptation in the highland deer mice.
Students should provide an answer that is consistent with the film and the definition of an adaptation. The following is a sample explanation:
Highland deer mice have an adaptation in their hemoglobin that allows them to carry more oxygen in their blood than lowland deer mice can.

4. List the conditions of natural selection (V, I, D, and/or A) that you observed in the video. Briefly describe how each condition you listed applies to the deer mice.
Students should provide reasonable explanations of which conditions they observed in the video. Some sample responses:
- ***Variation (V): The video shows that mice can have differences in the genes that code for their hemoglobin. Due to these differences, some mice have hemoglobin that is better able to bind oxygen.***

- ***Inheritance (I)*: Genetic differences can be inherited. So hemoglobin differences due to the genetic differences discussed in the video could be inherited.**
- ***Differential survival and reproduction (D)*: Highland deer mice with hemoglobin that can better bind oxygen would be more likely to survive in their low-oxygen environment. Mice without this trait might not be able to get enough oxygen and would thus be less likely to survive.**
- ***Adaptation (A)*: Over time, the frequency of the advantageous trait (hemoglobin that can better bind oxygen) would become more common in the highland deer population. That's why the scientists found that the highland population had strong genetic differences compared to the lowland population.**

5. Explain why the hemoglobin difference described in the video is advantageous to highland deer mice. Your answer should include the role of oxygen in the body.
   Oxygen is needed for essential processes in the body, such as using carbohydrates or fats to produce heat and ATP (usable energy). The hemoglobin in highland deer mice is better able to bind to and transport oxygen throughout the body. This is advantageous for the highland deer mice because they live in a low-oxygen environment and might not otherwise have enough oxygen to survive.

   More oxygen also allows highland deer mice to burn more fats, which produces more heat and ATP than burning carbohydrates. This makes it more likely for the mice to survive and reproduce in their very cold environments.

6. If a population of lowland deer mice was moved to a high-elevation environment, do you think the population could adapt in the long term? Explain your reasoning using the conditions in Table 1.
   Most responses are acceptable, as long as the student provides logical reasoning that supports their position. The following is a sample answer:
   I predict that the lowland deer mice would be able to adapt over many generations, as long as they have genetic variations in their population that would help with surviving in the high-elevation environment. This could include variations that make their hemoglobin better able to bind oxygen, give them longer or thicker fur, or enable them to produce more ATP and heat. The mice with an advantageous trait would be more likely to survive and reproduce, thereby passing this advantageous trait to the next generation. Eventually, over many generations, most of the population would have the trait.

EXTENSION: HUMAN ADAPTATIONS IN MOUNTAIN REGIONS

1. Which of the following might be used more in mountain regions compared to sea-level regions?
   a. *Fats*

2. Based on the excerpt, propose a hypothesis about how differences in oxygen (O_2) usage by the muscles might help Sherpas survive at high elevations (or altitudes).
   Most responses are acceptable, as long as the student provides logical reasoning that supports their position. High-level responses should include a comparison of the Sherpa population with human populations living at low elevations.

   The following is a sample correct response:
   Sherpas' muscles may use less oxygen to produce the same amount of energy as those of humans living at low elevations. This could help Sherpas survive at high elevations where oxygen is less available, since they might not be able to get enough energy otherwise.

Optional Extensions

- You can introduce students to individual reactions or cycles in cellular respiration. Students who are interested in pursuing AP Biology, or current college students, could greatly benefit from this type of exploration. The student deliverable, for example, could be a diagram or model of all molecules involved in the process.

- You can use the *Biomolecules on the Menu* Click & Learn to explore the connection between food molecules, the digestive system, and cellular respiration. This resource includes an interactive diagram of the main molecules and processes in cellular respiration.
- BioInteractive also has more detailed 3D animations of glycolysis, pyruvate dehydrogenase, citric acid cycle, electron transport chain, ATP synthesis, and ATP in use.

- Students interested in learning more about hemoglobin could explore resources on sickle cell disease.
  - The BioInteractive video *A Genetic Treatment for Sickle Cell Disease* could be used as an introduction.
  - Students could conduct online research to gather more information and create a deliverable (e.g., report or presentation) that relates sickle cell disease to DNA mutations and protein structure/function. The *Central Dogma and Genetic Medicine* Click & Learn includes a short case study on sickle cell disease (under "Transcription" and "Gene Switches") that can be used to supplement student learning/research.
  - If your class recently completed studies on heredity, it may be helpful for them to instead focus on hereditary disease patterns, particularly for autosomal recessive disorders.

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