In this minds-on, hands-on activity, students develop their understanding of natural selection by analyzing specific examples and carrying out a simulation. The questions in the introductory section introduce students to the basic process of natural selection, including key concepts and vocabulary. The second section includes a simulation activity, data analysis, and interpretation questions to deepen students' understanding of natural selection. In the third section, students interpret evidence concerning natural selection in the peppered moth and answer questions designed to consolidate a scientifically accurate understanding of how the process of natural selection can result in evolutionary change.

We estimate that it will take roughly 150 minutes to complete these three sections with an average class of high school students or with a relatively advanced class of middle school students. (For students with poor graphing skills, you will probably need more time.)

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Learning Goals
Learning Goals Related to National Standards
In accord with the Next Generation Science Standards and A Framework for K-12 Science Education:
• Students will gain understanding of two Disciplinary Core Ideas:
  o LS4.B Natural Selection. "Natural selection occurs only if there is both (1) variation in the genetic information between organisms in the population and (2) variation in the expression of that genetic information – that is, trait variation – that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population."
  o LS4.C Adaptation. "Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change."

1 by Drs. Ingrid Waldron and Jennifer Doherty, Department of Biology, University of Pennsylvania, © 2017. These Teacher Preparation Notes and two versions of the Student Handout for this activity are available at http://serendip.brynmawr.edu/exchange/waldron/naturalselection.
3 http://www.nap.edu/catalog.php?record_id=13165
• Students will engage in several **Scientific Practices:**
  o developing and using models
  o using mathematics
  o analyzing and interpreting data
  o constructing explanations
  o arguing from evidence.
• This activity provides the opportunity to discuss the **Crosscutting Concepts:**
  o Cause and effect: Mechanism and explanation – Students “suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems.”
  o Systems and system models – Students can “use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models.”
  o Stability and change – “Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems . . .”
This activity helps to prepare students for the **Performance Expectations:**
  o MS-LS4-4, "Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment."
  o MS-LS4-6, "Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time."
  o HS-LS4-2, "Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment."
  o HS-LS4-3, "Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait."
  o HS-LS4-4, "Construct an explanation based on evidence for how natural selection leads to adaptation of populations."

**Specific Learning Goals**
• Different individuals in a population have different characteristics; this is **variation.**
• **Fitness** is the ability to survive and reproduce.
• A characteristic which is influenced by genes and can be inherited by a parent’s offspring is called a **heritable trait.**
• A heritable trait that increases fitness is an **adaptation.**
• An adaptation tends to become more common in a population. Because the adaptation increases fitness, individuals with this trait generally produce more offspring. Because the trait is heritable, offspring generally have the same trait as their parents. Therefore, the adaptation tends to become more common in the population. This process is called **natural selection.**
• Natural selection results in changes in the frequency of an adaptation in a population. Natural selection does **not** cause changes in an individual.
• Evolution by natural selection occurs if and only if there is variation in a heritable trait which contributes to differences in fitness.
• Which characteristics are adaptations and how a population evolves depend on which type of environment the population is in. The same population will evolve differently in different environments.
• In biological populations, evolution by natural selection usually occurs slowly over many generations.

This activity counteracts several common misconceptions about evolution⁴:
• Individual organisms can evolve during a single lifespan.
• Natural selection involves organisms trying to adapt.
• The "needs" of organisms account for the changes in populations over time (goal-directed or teleological interpretation).
• The fittest organisms in a population are those that are strongest, fastest, and/or largest.

Equipment and Supplies for Section II. Simulation of Natural Selection
• 2-3 yards of black cloth for the black forest habitat (should be faux fur or some other rough cloth) The size of the habitat should accommodate foraging by half the students in your class.⁵
• 2-3 yards of red cloth for the red grasslands habitat (should be fleece, with a different texture than the black habitat)
• 5 or 7 mm black and red pom-poms (250-300 of each color per class)
The specific colors of the pom-poms and habitats need not be black and red, so long as there is a very good color match between each habitat and one color of the pom-poms. Both color cloths should be textured, since even pom-poms of a matching color tend to be readily visible on plain flat cloth. If possible, the textures should be as deep as or deeper than the diameter of the pom-poms. The textures should be different to demonstrate that different hunter adaptations may be more successful in different habitats.⁶
• Plastic forks and spoons for hunter feeding structures (1 of each for each student)⁷

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⁴ Most of these misconceptions are excerpted from Misconceptions about evolution, available at http://evolution.berkeley.edu/evolibrary/misconceptions_teacherfaq.php

⁵ A version of the simulation with only one habitat is available as an attachment at http://serendip.brynmawr.edu/exchange/waldron/naturalselection. This version may be suitable if you have a small class (<14-16 students), limited funds for purchasing the habitat cloth (for a cheaper alternative, see footnote 6), or students who require close supervision (you may want to have a subset of your students perform the simulation as a demonstration). If you use this one-habitat version, you will need to adapt some of these Teacher Preparation Notes accordingly. Also, depending on the type of cloth you purchase, you may want to replace Black Forest with Red Grassland in the shorter Student Handout.

⁶ This simulation can also be done with two different color poster board habitats and squares or circles of the same colors as the two habitats to serve as the prey; the student predators can use their fingers or tweezers. This is more economical than using cloth and pom-poms, at least in the short term. We prefer cloth that meets the above specifications, but poster board habitats and matching circles or squares will probably give better results than using cloth which is not highly textured and/or is a poor color match for the pom-poms. Some natural selection simulation activities suggest using beans, but we recommend against this. Beans of different colors often vary in size and weight and it is difficult to find a good color match for the background. These problems tend to distort the results of simulations that use beans.

⁷ Fork and spoon feeding structures have different fitness on some textured fabrics, but you may not see a difference in fitness between fork and spoon feeding structures, particularly if you have fewer than 10 hunters on each habitat. If you want to ensure that there will be a difference in fitness between the two types of feeding structures, you can substitute plastic knives for either the forks or the spoons and make appropriate changes in the wording of the Student Handout and Instructions for Student Helpers.
- Cups for hunter stomachs (1 per student) (To make the hunting task a little more challenging, you can use small plastic test tubes or the small plastic tubes that florists put on the ends of cut roses. If you anticipate that your students may be prone to cheat by laying their cups on the habitat and shoveling multiple pom-poms in with their feeding structure, you may prefer to use plastic bottles with narrow necks for the hunter stomachs.)

- Calculators for calculating percents (page 5 of Student Handout)

- Some way to time the feeding times (typically 10-15 seconds)

**General Instructional Suggestions**


To maximize student learning, we recommend that you have your students **complete groups of related analysis and discussion questions individually, in pairs or in small groups** and then have a class discussion for each group of related questions. In their responses to these questions, students are likely to include some of the misconceptions listed on page 2 of these Teacher Notes. When these misconceptions come up in the whole class discussions, thoughtful questions often can elicit more accurate interpretations from your students.

A **key** for this activity is available upon request to Ingrid Waldron ([iwaldron@sas.upenn.edu](mailto:iwaldron@sas.upenn.edu)).

The following paragraphs provide additional instructional suggestions and biological information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

**Background Biology and Instructional Suggestions for Section I. Mice Living in a Desert**

In the Student Handout, fitness is defined as the ability to survive and reproduce. A more general definition for fitness is "the extent to which an individual contributes genes to future generations..." (from *Evolutionary Analysis* by Freeman and Herron).

Students should understand that, in discussing natural selection, we use the word "adaptation" to refer to a heritable trait that increases survival and reproduction. This differs from the common usage of adapting to the environment which refers to changes in an organism's characteristics during its lifetime. To help your students understand this distinction, you may want to use the follow-up activity "Evolution and Adaptations" ([http://serendip.brynmawr.edu/exchange/bioactivities/evoadapt](http://serendip.brynmawr.edu/exchange/bioactivities/evoadapt)).

When you discuss question 7, you may want to emphasize that organisms are not evolving to some pre-ordained “perfection” but are evolving to greater fitness in a given environment.

One limitation of this activity is that most of the examples relate to camouflage. Question 8 will provide the opportunity for you to discuss with your students the **great variety of adaptations** that have resulted from natural selection, including anatomical, physiological, molecular and behavioral adaptations.

You may want to discuss with your students how questions 5-8 illustrate the Crosscutting Concept, Cause and effect: Mechanism and explanation – Students “suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems.”
You may want to develop a synthesis consensus model of natural selection with your students at the end of Section I and post this in your classroom. Then you can expand and improve this model as you proceed.

**Instructional Suggestions for Section II. Simulation of Natural Selection**

1. **Before** the class period when you will do the simulation:
   a. Count out 2 batches of 90 pom-poms, with 45 pom-poms of each color in each batch. (If you have a particularly large class, you may want to have 60 pom-poms of each color in each batch.)
   b. Scatter 45 black and 45 red pom-poms in each habitat. (The simulation works better if students do not have time to overcome the camouflage by searching for pom-poms ahead of time, so you may want to fold each habitat with pom-poms in half and unfold the habitats just before beginning the simulation.)
   c. To speed the simulation activity, you will want to sort the remaining pom-poms into groups of 10 and 20 of the same color, ready to be included in the pom-poms that you will scatter for the second round of the simulation. To have the groups of 10 and 20 pom-poms of the same color ready for easy use, you may want to put them in a tray with compartments (e.g. ice cube tray or bead tray).
   d. For each class you teach, you will need a copy of the data table on the next page. Record the number of pom-poms of each color for generation 1. Alternatively, you may want to prepare an Excel file version of the table.
   e. For each habitat in each class, choose a student helper who will help to organize the simulation procedure. Give each of them a copy of the Simulation Instructions for Student Helpers (provided on the last two pages of these Teacher Preparation Notes). The activity will go more smoothly if your student helpers have a chance to read these instructions before the simulation begins.
   f. Draw or project this table on the board.

<table>
<thead>
<tr>
<th>Number who have this feeding structure in:</th>
<th>Hunters in the Black Forest</th>
<th>Hunters in the Red Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation 1</td>
<td>Spoon</td>
<td>Fork</td>
</tr>
<tr>
<td>Generation 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. When you are ready to begin the simulation, split the class in half (with each half becoming the hunters on one of the habitats). You may want to have your students stand with their backs to the simulation habitat until you are ready to have them begin feeding; we have found that the simulation works better if students do not have time to overcome the camouflage by searching for pom-poms ahead of time. For each habitat, give each student a fork or spoon (one half each). Record the numbers of hunters with each type of feeding structure for generation 1 in the above table on the board.

3. Remind the students of the rules of the game (see the bottom of page 4 of the Student Handout).
   a. Remind them to pick up each pom-pom with their feeding structure and put it in the cup. They must keep their cups upright at all times and are not permitted to tilt the
cups and shovel pom-poms into them.
b. Competition for resources is okay, but once a pom-pom is on a feeding structure, it is off limits to other students.
c. Tell them how long they will have to feed. We have found that 15 seconds often works well, but you may need to adjust the number of seconds, depending on the number of students you have, cloth size, etc.

4. Start the students feeding and call stop after 15 seconds (or whatever time you have chosen).

5. After feeding, each student helper will lead the students in his or her habitat group in carrying out the instructions presented in the Simulation Instructions for Student Helpers (see pages 10-11 of these Teacher Preparation Notes).

6. Get the number of pom-poms of each color eaten in each habitat from your student helpers and use the chart below to calculate how many pom-poms of each color survived. Each surviving pom-pom reproduces, so, for each surviving pom-pom, you will add one offspring pom-pom of the same color. Scatter the appropriate number of additional pom-poms of each color on each habitat. To expedite the process, you may want to have student helpers scatter the pom-poms, but make sure that students do not scatter pom-poms on the same habitat where they will hunt.

<table>
<thead>
<tr>
<th>Habitat Type: Black Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pom-pom Color</td>
</tr>
<tr>
<td># in generation 1</td>
</tr>
<tr>
<td># eaten</td>
</tr>
<tr>
<td># surviving (# generation 1 - # eaten)</td>
</tr>
<tr>
<td>For each color, add one additional pom-pom for each surviving pom-pom.</td>
</tr>
<tr>
<td># in generation 2 (2 x # surviving)</td>
</tr>
<tr>
<td># eaten</td>
</tr>
<tr>
<td># surviving (# generation 2 - # eaten)</td>
</tr>
<tr>
<td># in generation 3 (2 x # surviving)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat Type: Red Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pom-pom Color</td>
</tr>
<tr>
<td># in generation 1</td>
</tr>
<tr>
<td># eaten</td>
</tr>
<tr>
<td># surviving (# generation 1 - # eaten)</td>
</tr>
<tr>
<td>For each color, add one additional pom-pom for each surviving pom-pom.</td>
</tr>
<tr>
<td># in generation 2 (2 x # surviving)</td>
</tr>
<tr>
<td># eaten</td>
</tr>
<tr>
<td># surviving (# generation 2 - # eaten)</td>
</tr>
<tr>
<td># in generation 3 (2 x # surviving)</td>
</tr>
</tbody>
</table>

7. Once the new pom-poms have been scattered on the habitats and everyone has their feeding structures for the second generation, start the second round.

8. After the second round is finished, repeat steps 5-6 above. After the student helpers record hunter numbers for generation 3, the students return to their seats and answer question 11 of the Student Handout.
Use the information from the data table on the previous page to display the numbers of red and black pom-poms for each generation in each habitat. Your students will record the results in the table in question 12 of the Student Handout. Then, your students will calculate the total number of pom-poms and the percentages of each color for each generation in each habitat and complete the graphs in question 13. We recommend that you have your students make dot and line graphs similar to the graph shown on page 9 of the Student Handout.

Use **questions 11 and 14-15** of the Student Handout to guide your students in interpreting the results of the simulation and developing their understanding of natural selection.

**Questions 16-18** are designed to help students **understand the necessary conditions for natural selection** by considering what would happen if any of these conditions is not met. In question 16b, students are asked whether natural selection could occur if the black forest habitat became red grassland due to a prolonged drought, but only black pom-poms had survived in the population. The simple answer is that without any variation there would be no opportunity for natural selection; however, more sophisticated students may point out that natural selection could occur if a mutation for red color occurred in the population or if red pom-poms migrated in from another population. These questions provide the opportunity to discuss the Crosscutting Concept, Stability and change – “Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems …”

To conclude this section we recommend a discussion of the **strengths and weaknesses of this simulation as a model of natural selection**. The strengths of this simulation include that it demonstrates the basic features of natural selection and helps to correct the following common misconceptions:

- Individual organisms can evolve during a single lifespan.
- Natural selection involves organisms trying to adapt.
- The fittest organisms in a population are those that are strongest, fastest, and/or largest.

There are several important differences between this simulation and natural selection in nature (see the bottom of page 7 of the Student Handout). In the simulation we assume that differences in survival and reproduction are due entirely to predation which can be reduced by camouflage. In contrast, in real biological populations there are other factors that influence mortality and reproductive success, independent of the effectiveness of camouflage. Also, in this simulation offspring are identical to their parents. In contrast, for sexually reproducing organisms, the characteristics of offspring are similar, but not identical to their parents. These differences between this simulation and biological reality help to explain why this simulation suggests that natural selection occurs much more rapidly than it actually does in nature. This illustrates a typical weakness of simulations – namely that they are simplified and omit important aspects of the actual biological process. The example presented in the next section of the activity illustrates that **natural selection typically is a gradual process that takes place over many generations**. This discussion will illustrate the Crosscutting Concept, Systems and system models – Students can “use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models.”
Background Biology and Instructional Suggestions for Section III. Natural Selection in Action – The Peppered Moth

As discussed on the bottom of page 8 of the Student Handout, the allele for melanism is dominant relative to the allele for the speckled form. These two alleles are the most common alleles in the populations studied. Depending on your students, you may want to challenge your students to complete the Punnett squares in question 20 instead of providing already completed Punnett squares.

There has been some controversy concerning the cause of the trends in the speckled and black forms of the peppered moth (see "Industrial Melanism in the Peppered Moth, Biston betularia: An Excellent Teaching Example of Darwinian Evolution in Action", Evo Edu Outreach (2009) 2:63-74). Some aspects of this controversy have been beneficial since they have identified flaws in some of the earlier research and stimulated improved research which has provided strong evidence for the importance of natural selection due to predation by birds on peppered moths (see e. g. http://rsbl.royalsocietypublishing.org/content/roybiolett/8/4/609.full.pdf).

Bats are also important predators on adult male peppered moths (the females fly very little so they are less subject to bat predation). However, unlike birds, bats are not visual predators and are equally likely to eat speckled or black peppered moths. The caterpillars of the peppered moth are presumably also subject to predation, and these caterpillars have a different type of camouflage that is independent of the adult black versus speckled forms. When caterpillars molt, they can change color to match the color of the twigs that they rest on. The evidence indicates that bat predation, predation on caterpillars, and other causes of mortality appear to be generally equal for both color forms of adult peppered moths; therefore, the selective disadvantage for the color form of the adult peppered moth that is mismatched with the environment is not nearly as strong as we might expect. This is a major reason for the slower trend in the percent of peppered moths that are black, even though air pollution decreased more rapidly following government regulation.

One goal of question 23 is to counteract the common misconception that the "needs" of organisms account for the changes in populations over time (goal-directed or teleological interpretation). A complete explanation of change as a result of natural selection should include a description of how a trait contributes to an improved chance of survival and reproduction, an assertion (preferably with evidence) that the trait is heritable, and a description of how this adaptation becomes more common in the population over time.

Follow-up Activities

“Evolution of Fur Color in Mice – Mutation, Environment and Natural Selection” (http://serendip.brynmawr.edu/exchange/bioactivities/NaturalSelectionMice)
This analysis and discussion activity reinforces student understanding of natural selection. Students view a brief video that presents research findings concerning the roles of mutation and natural selection in the evolution of fur color in rock pocket mice. Questions in the video and in the Student Handout guide students to a deeper understanding of natural selection, including how natural selection varies depending on the environment, how convergent evolution occurs, and

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8 This is an example of phenotypic plasticity (the ability to adapt to different environments with in an organism’s lifetime). The analysis and discussion activity, “Evolution and Adaptations” (http://serendip.brynmawr.edu/exchange/bioactivities/evoadapt) helps students to understand natural selection for phenotypic plasticity, including the ability of an octopus to rapidly change color and pattern to match its current environment.
how analysis at multiple levels from the molecular to the ecological contributes to a better understanding of evolution by natural selection.

Additional recommended resources for teaching and learning about evolution are presented in http://serendip.brynmawr.edu/exchange/bioactivities/evolrec.
Simulation Instructions for Student Helpers

1. Have the students in your group count how many pom-poms they have in their cups and line up in order of how many pom-poms they have (least to most).

2. Go down the line and record how many pom-poms of each color were eaten and the feeding structure (F = fork; S = spoon) for each hunter in Generation 1. Remind the students in your group that:
   - They should give you the pom-poms that they have eaten. These pom-poms are dead, so they should not be put back on the habitat.
   - The students should also give you their feeding structures, since each hunter only survives for one round of hunting.

3. Calculate the total number of red pom-poms eaten and the total number of black pom-poms eaten and give these numbers to your teacher.

4. The half of the students who ate the most pom-poms survive long enough to reproduce. Each of these students will have two “offspring” with the same feeding structure as the “parent”. In the table above, circle the feeding structures for the half of the students who ate the most pom-poms. If you have an odd number of students in your group, see C in the table below. Complete the table below to calculate the number of hunters with each type of feeding structure in Generation 2.

5. Record the number of Generation 2 hunters with forks and the number of Generation 2 hunters with spoons in the appropriate row in the table on the board. Distribute forks and spoons to the hunters in your group so you have the right number of Generation 2 hunters with each type of feeding structure.

6. Next, your group should discuss the questions at the top of page 5 of the Student Handout.
7. After the second round of the simulation, repeat the same procedure, using the table below to record the data for pom-poms and feeding structures. Tell your teacher the number of red pom-poms eaten and the number of black pom-poms eaten.

<table>
<thead>
<tr>
<th>Hunter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td># Black Pom-Poms Eaten</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Red Pom-Poms Eaten</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Feeding Structure in Generation 2</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. Complete the table below to calculate the number of hunters with each type of feeding structure in Generation 3.

<table>
<thead>
<tr>
<th></th>
<th>Fork</th>
<th>Spoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Number of hunters with this feeding structure who were in the top half of pom-poms eaten</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Number of offspring with this feeding structure (2 x number in A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. If there are an odd number of students in your group, the student in the middle for number of pom-poms eaten, produces one offspring, so enter a 1 in the appropriate column.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Total number of Generation 3 hunters with this feeding structure (B+ C)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. Record the number of Generation 3 hunters with forks and the number of Generation 3 hunters with spoons in the table on the board.

10. Each student should return to his or her seat and answer question 11 on page 5 of the Student Handout.