Unit 10: Behavior

Biology in a Box

A science education outreach program brought to you by a partnership between The University of Tennessee and the National Institute for Mathematical and Biological Synthesis

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Unit 10: Behavior
Materials List

Exercise 1

- Set of 6 student tactile boxes (glued shut)
- 1 teacher tactile box (openable)
- 6 "White Box" tins, each containing:
  - Cork
  - Cotton ball
  - Crayon
  - Marble
  - Metal ball
  - Paper clip
  - Penny
  - Poker chip
  - Rubber ball
  - Rubber band
  - Toothpick
- 6 "Black Box 1.3a" containers (openable), each containing 2 items
- 6 "Black Box 1.3c" containers (screwed shut)
- 1 "Teacher Container" containing
  - Replacement "White Box"/"Black Box" materials
  - 12 replacement screws
- 6 magnets
- 6 empty plastic Solo cups
- 6 spring scales or digital scales
- 6 hair nets (if unit has spring scales)
- 6 100g calibration masses (if unit has digital scales)

Exercise 2

- 6 olfaction jars with red dot
- 6 olfaction jars with blue dot
- 3 olfaction jars with green dot (bee, butterfly, fly)
- Deely-bopper (headband with antennae)

Exercise 3

- 2 silk flowers with tubes attached
- Bag of small pom poms
- Bag of coffee stirrer straws
- 6 decks of 25 "Alarm" cards
- 3 decks of 25 "Mimic 1" cards
- 3 decks of 25 "Mimic 2" cards

Exercise 4

- Blindfold
- Wood block with attached monofilament line

Exercise 5

- *Biology in a Box* Unit 10 CD

Exercise 6

6 T-mazes

Exercise 7

- 1 container with cloth bag
- 6 copies of the "Caching Game" with
- 40 blank chips of one color
- 6 acorn chips of same color
- 4 chips of different color
- 1 game mat

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Introduction

This unit is all about behavior. You can probably think of many examples of behavior, but what exactly *is* behavior? All **behavior** involves ***actions by organisms in response to particular situations***. Behavior thus involves **responses** to **stimuli** or cues. Some of these stimuli may be internal (generated within the organism itself) such as an empty stomach generating hunger (with a hungry animal seeking food, or a "hungry" plant growing towards sunlight). Actions may also be in response to external cues. For instance, a rabbit freezes in place when it detects a predator, and runs from a pursuing predator in a zig-zag pattern. In this case, predator presence and pursuit are the stimuli that cue the "freeze" and "zig-zag run" responses, respectively.

In order for an animal, or any organism for that matter, to respond to internal and external cues, it also must have the means to *detect* these cues. Organisms vary in the extent to which they utilize vision, hearing, smell and touch in detecting objects and events. The senses, like actions, are also components of behavior.

Finally, just as an organism's size, shape, and color adapt it to the environment in which it lives, behavior is also adaptive and can be inherited, or passed on from parent to offspring. All organisms exhibit behavior, even bacteria, though, of course, it is most important to animals that are able to move in complex ways. In this unit, you will learn the ways in which behavioral traits contribute to the success of individuals and the species they represent. In **Part I** of this workbook, you will examine the various senses utilized by various animals, as well as their relative importance in different organisms. In **Part II**, you will examine the roles of environmental influences and learning, and their contribution to behavior.

Part I: The Senses

Senses provide an animal access to external information. They also filter information from the external environment, determining what an animal tunes into and what it does not. While we usually think in terms of the so-called "five senses" (taste, touch, hearing, vision, and smell), there are additional senses, such as the perception of magnetic fields, heat, and electricity. There are also many variations of each of the individual senses mentioned above. Variability exists because sensory systems have developed for different functions. Thus, different organisms sense the world in different ways. For instance, humans largely utilize vision and hearing to filter cues from our environment. However, an earthworm in the soil or a fish in a body of water is tuned primarily to vibrations and odors. In the following exercises, have fun experimenting with your own sensory capabilities as well as experiencing the world from the viewpoint of animals that have different sensory capacities.

In **Exercise 1: The Tactile Sense (Touch)**, you can explore your sense of touch through the use of the included Tactile Boxes, and through various "Black Box" experiments.

Exercise 2: Chemical Olfaction (Smell) is devoted to the sense of **olfaction**, which, similar to the sense of taste, is a sense involving the perception of chemical substances. In this exercise, you will examine how well you can distinguish smells on both coarse and fine scales, as well as learn about the relative importance of this sense in different groups of insects.

Exercise 3: Vision examines the visual sense, as well as its importance in finding food and mates in various animals.

Finally, **Exercise 4: Hearing is a Vibrational Sense** explores the science of sound and how it is perceived in a broad range of organisms.

Exercise 1: The Tactile Sense (Touch)

While the other senses are limited to special organs in the body, such as vision with eyes, hearing with ears, smell with the nose (in mammals and birds at least), the **tactile** sense (touch) is perceived by receptors all over the body just below the surface layer of skin in the **dermis** layer. Here thousands of **sensory cells** (**nerve endings**) detect pressure/weight, temperature, pain, and other lesser stimuli. For example, your sense of touch also allows you to tell the difference between various textures, such as rough and smooth, soft and hard, wet and dry, sticky and smooth, etc. Locations that are more sensitive to external cues (your fingertips, lips, and tongue, for example) have large concentrations of these nerve endings. Why do you think this might be the case? In these exercises, you will determine how well your sense of touch works, as well as learn about how other animals use this sense.

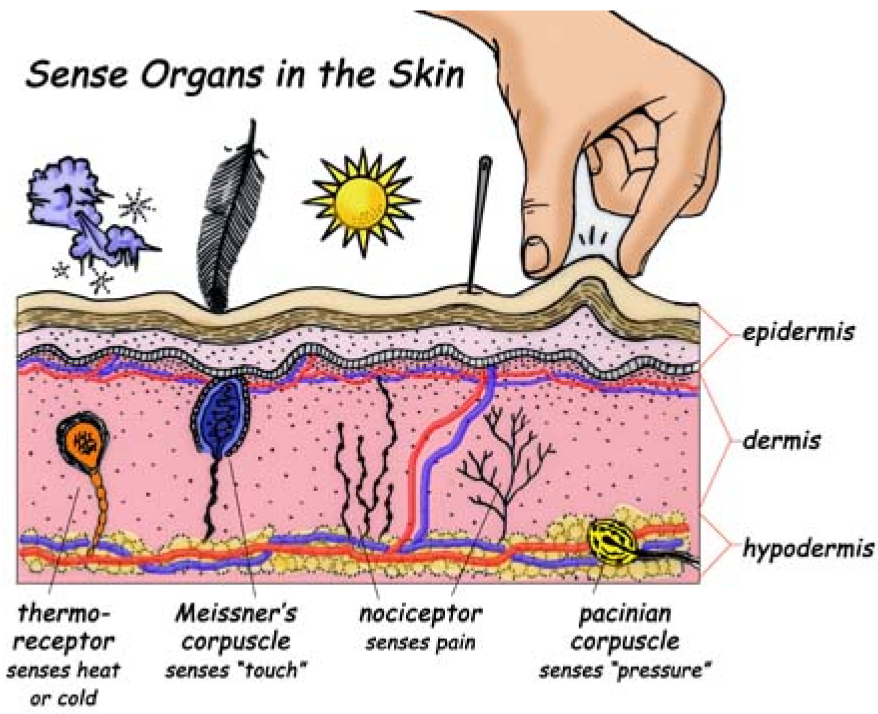


Diagram of various receptor cells in human skin. Amsel, Sheri. "Special Senses." Touch. Exploring Nature Educational Resource. © 2005 - 2012. February 23, 2012. <http://exploringnature.org/db/detail.php?dbID=25&detID=47>

Exercise 1.1: The Tactile Box (*Grades K-1*)

Materials:
- Tactile Boxes
- Touch Sense Chart (Teachers can provide copies of the chart on page 5, or have students make their own)

In this exercise, your sense of touch becomes your only guide.

Instructions:

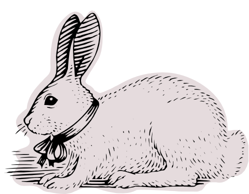
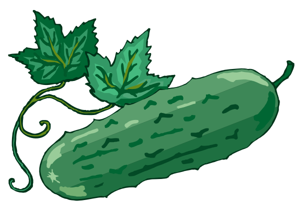
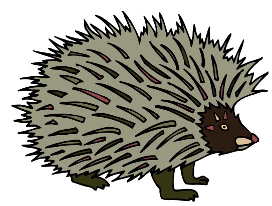
- Divide into groups of 4-5 students each.
- Your teacher will provide each group with a tactile box (which is glued shut). **Do not peek inside the hole on top!**
- Note that one side of the box (the top) has an opening that is masked by a sheet of foam with cuts in it. This will allow you to place one or more fingers inside the box without seeing into it. On the inside of the box, there are different textures on 5 surfaces (all four inner sides, and the inner bottom) of the box:
    - One surface will feel rough or prickly.
    - One surface will feel soft or fluffy.
    - One surface will feel smooth.
    - One surface will feel sticky.
    - One surface will feel bumpy.

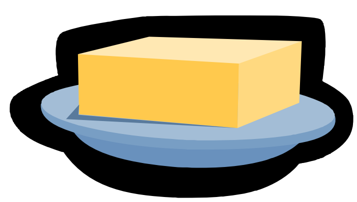
Your goal is to find each of these surfaces by using only your sense of touch.

- Slip your hand (in the case of larger wooden boxes) or a few fingers (in the case of smaller metal boxes) into the hole on the top of the box. **Don't try to peek inside!**
- Touch one of the inner surfaces and run your hand or fingers along it.
- Take note of how this particular surface feels.
- Next, look at the picture on the outside of the box that corresponds to the surface you are touching.
- Make a chart like the one shown on page 5 (or your teacher will provide one for you).
- Find the picture on the chart that matches picture on the outside surface that you just felt. Write one of the words (fluffy, bumpy, scratchy, sticky, or smooth) that best describes the texture beside the matching picture on the chart.

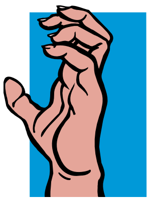
NOTE FOR TEACHERS: Students that have not yet reached reading/writing proficiency can be asked to draw a picture that corresponds with the appropriate texture. For example, a bunny for "fluffy," a cucumber for "bumpy," a porcupine for "prickly," a jar of honey for "sticky," and a stick of butter for "smooth". Alternatively, you can copy the pictures below and have students cut and paste/tape these pictures in the appropriate area of the chart.

- Once you have determined done this for one inner surface, go on to each of the other walls, filling in your chart as you work until you have examined all of the wall coverings in the box.
- Compare your results with other students in your class.
- Finally, check your chart against the one in the answers at the end of this workbook.



Tactile Box Chart

Outside Picture	Inside Texture
 **Hand / Claws**	
 **Foot**	
 **Flower**	
 **Butterfly**	
 **Frog**	

Exercise 1.2a: What is the object in my box? *(Grades K-3)*

NOTE FOR KINDERGARTEN TEACHERS: The sorting activity in this exercise can be done without students constructing the characteristics/attribute table. The sorting activities address Standard 5 - Data, Probability, and Statistics for Kindergarten.

Introduction:

In Exercise 1.1, you decided what different surfaces feel like. Animals also use the sense of touch to identify objects. In this exercise, you will also use your sense of touch to identify mystery objects. You will also learn a little about probability, and how it is important to science, as well as many other fields.

When we talk about the chance that a particular event will happen, we are talking about **probability**. We hear about the chance of rain, the chance of snow, or the chance that any particular weather event will happen. That means that we are hearing about the *probability* of a particular weather condition occurring. We also hear about the chance of winning the lottery, which is really the *probability* that we will win.

Making predictions about the likelihood of a certain event happening is a very important skill, and helps us in many areas of our lives. Aside from just useful information about the weather and the lottery, understanding probability is very useful in studying health and disease, transportation safety, sports, and protecting the environment, just to name a few.

First let's further explore your tactile sense.

- Form a line with other students to approach the front of the classroom.
- When it is your turn, go to the front of the room one at a time with your hands behind your back, and turn to face the class.
- The teacher will place an object in your hand to feel but not see.
- Go back to your desk without talking to others
- After everyone has had the opportunity to feel the object, your teacher will poll the class as to what everyone thought the object was.
- Once a list of potential objects has been made and all students have had the opportunity to discuss the characteristics of the object that gave them a clue as to what it was, the object will be shown to the class.

Now let's repeat this game, but with a slight twist. This time you will have the opportunity to examine all of the objects that might possibly be given to you before you feel the mystery object.

- Divide into small groups of around 4 students each.
- Your teacher will provide each group with a container (the "White Box" container) of 11 objects, including the following items: a cork, a cotton ball, a crayon, a marble, a metal ball, a paper clip, a penny, a poker chip, a rubber ball, a rubber band, and a toothpick.
- Your teacher will also place one of the objects found in the White Box you have to look at in the tactile box your group will receive. It is your job to determine what is in this mystery box. Do not peek or reach into the tactile box given to you!
- Look carefully at each of the items in the provided "White Box" container. What do you notice about each item? The words you use to describe the items, "shiny," "smooth," "round," etc., are called **characteristics**, or sometimes they are called **attributes**.
- Look at the **geometric characteristics** (shapes) of each object. For example, is the object ball-shaped, flat, rectangular, round, etc.? Compare your observations of the different objects.
- Now examine the objects for other characteristics. How do they feel? Are they smooth, rough, soft, or hard? Are some heavier than others?
- Now select two characteristics for sorting the items into two separate groups. Make a two-column chart with one of the chosen characteristics at the top of each column. Sort the items in the White Box and write the names of the items in the column that best describes each item.
- Put all items back together in one group. Sort the items a second time, only this time using two different characteristics. Write down the second set of characteristics and the items in each group as done in the first sorting.
- Discuss with your classmates and teacher about your choices of characteristics and how those characteristics could help you determine which object is in a team's tactile box. In discussing these characteristics, consider the following questions:
  - Which characteristics will be helpful to you when you are trying to determine which object is in the box? If so, how will they help you? If not, why not?
  - Why did you choose particular characteristics? Did all items clearly fit into one or the other group? Were your characteristics "opposites" (hard versus soft, smooth versus rough, etc.)?

- Now repeat the mystery object tactile game a second time with the information you have gained about the characteristics of the potential objects available to you.
- You should again form a line to approach the front of the room one at a time, again with your hands behind your back, and turning to face the class.
- The teacher will again place an object in your hand to feel but not see.
- Go back to your desk without talking to others.
- After everyone has had the opportunity to feel the object, your teacher will again poll the class as to what everyone thought the object was.
- Once a list of potential objects has been made and all students have had the opportunity to discuss the characteristics of the object that gave them a clue as to what it was, the object will be shown to the class.
- Discuss with your classmates whether this second version of the game was easier for you. If so, why do you think that is the case?

Exercise 1.2b: What is the Object in my Box? (*Grades 4-12*)

- Read the instructions for the previous exercise (1.2a), then go on to the following information.

How likely do you think it is that a ball-shaped object (sphere) will be placed in your hand? How likely do you think it is that a flat object will be placed in your hand? How many individual outcomes are possible, knowing that one object will be placed in your hand? These are questions that can be answered by ***simple probability.*** When we think about how likely, or how *probable*, it is that a certain object will be given to us, we have to first think about all the possible outcomes. We know there are 11 possibilities, because there are 11 different objects that could be chosen as the one placed in your hand. For example, the probability that it is a rubber band is 1 out of 11, because only one of the 11 objects is a rubber band. The probability of a sphere being the object is 4 out of 11, because 4 of the 11 objects (cotton ball, marble, metal ball, rubber ball) are spheres.

There are several ways to write probability symbolically. You may see probabilities written as

$$\mathbf{3:11}\ \boldsymbol{or}\ \mathbf{\frac{3}{11}}\ \boldsymbol{or}\ \text{"}\mathbf{3}\ \boldsymbol{out\ of}\ \mathbf{11}\text{"}$$

Even though these all look slightly different, they all tell us the same thing: **the number of chances for a particular occurrence out of the *total* chances of all**

possible occurrences. In other words, they all tell us how likely a particular occurrence is.

- Now choose a characteristic and find the probability of an object with that characteristic being the item placed in your hand. Write the probability in three different ways as described above.
- Working with your teammates from the exercise above, quiz each other on the probability of various objects in the White Box of being handed to you.

Exercise 1.3: The Black Box: How Science Works (*Grades 3-12*)

What is **science**? It can be defined as any approach that involves the gaining of knowledge to explain the natural world. The scientist tests ideas by gathering evidence. A popular opinion of science has been that it is done in a very specific way, always following a set number and order of steps. This is not the case. Science actually is a very creative endeavor and consists of the interaction of elements, such as exploration and discovery, community interaction, and contributions to society, while still maintaining the central notion of testing ideas. For an illustration of the ways in which these elements of science interact, see Figure 1 below offered by the University of California Museum of Paleontology at UC Berkeley. Visit their site for a more detailed examination of the interactions of the areas depicted in the figure.

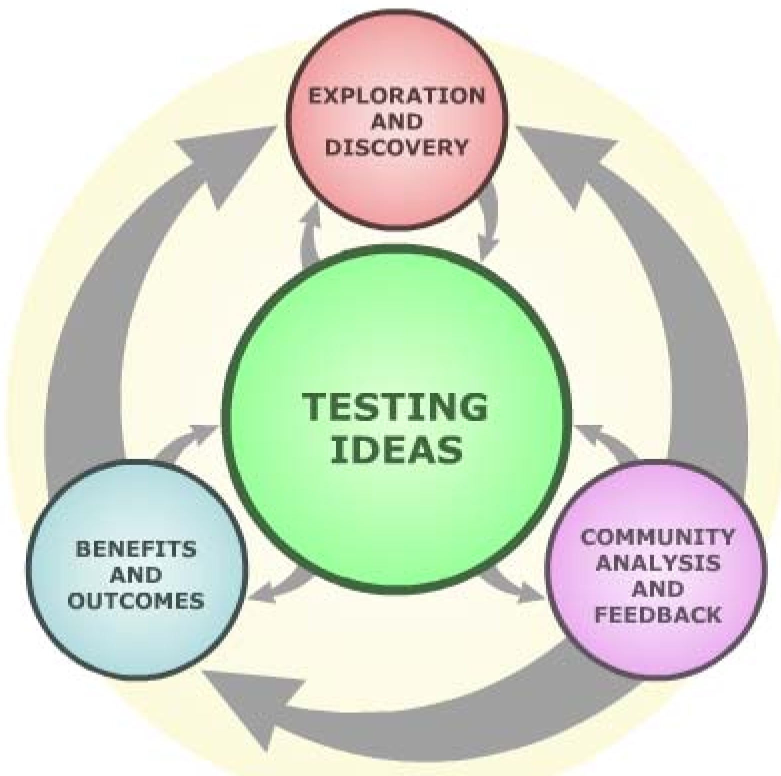


Fig. 1 Interaction of the various elements of science, including the central focus of testing ideas.
Understanding Science. 2012. University of California Museum of Paleontology. 3 January 2012 <http://www.understandingscience.org>

In this series of exercises, collectively referred to as 'Black Box' experiments, you will first focus on the fundamental principle of testing ideas (see Fig. 2 below), but expand your view of science, and how other different elements of science (such as discovery, community interaction, and benefits to society) can interact and contribute to the exciting field of science as a whole.

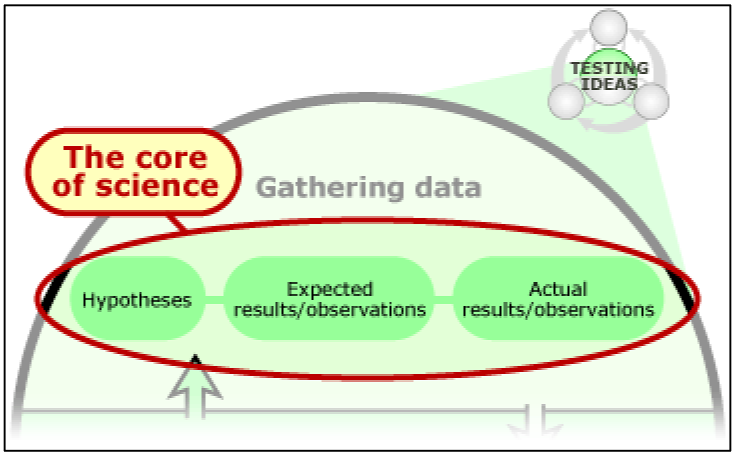


Figure 2. Hypothesis testing. Understanding Science. 2012. University of California Museum of Paleontology. 3 January 2012 <http://www.understandingscience.org>

When it comes to testing ideas, you will often hear about the testing of a particular hypothesis. Hypotheses are referred to as "educated guesses," which are potential explanations of a particular natural phenomenon. For example, let's say you have two flower beds in which you have planted seeds from the same seed packet. One flower bed is in your front yard and the other in your back yard. When you examine the plants that have been produced by the seeds, you observe that those in the front yard flower bed are much taller than those in the back yard. You could come up with several possible explanations (hypotheses) as to ***why*** this might be the case. For example, you might argue that the flower bed in the front yard gets more sun, gets or retains more moisture, has better soil quality, or even some combination of these and other factors not listed. Each of these possible explanations is an idea that could be tested.

Let's assume, that you decide to test your hypothesis that the flowers in the front yard are taller because you think the front yard receives more light. What kinds of evidence would you gather to test this idea and would you make an assumption about some aspect of your hypothesis that you will not be testing directly? (By assumption, we refer to something that is accepted as fact without proving it first hand). Well, first, you could do something simple, such as placing light meters in each flower bed to record the amount and intensity of light that each received throughout a particular time period. If in comparing the light records between flower beds you find that the light meter readings from the front yard bed reflect, on average greater light exposure than those collected from the back yard bed, then your hypothesis is supported.

The assumption you might then make based on your knowledge of the factors that influence plant growth is that increased light is contributing to the production of taller plants in the front yard. You could actually test this assumption directly by setting up an experiment with a new package of seeds of that flower species, growing them under different light levels. In this case, you would predict, before the flowers started to grow, that the seeds exposed to more light would grow taller.

In the two experiments described above, you would be gathering evidence to test your hypothesis that light exposure differences may lead to differences in plant growth. The results of tests of ideas may either support or fail to support a particular hypothesis. If the results fail to support the original hypothesis, a new, revised hypothesis can then be formed and tested. If, however, the hypothesis is supported by the results, that doesn't necessarily mean a stopping point has been reached. Just because: 1) there is a correlation between the amount of light the two sections of your yard receives and plant height; and 2) that light contributes to plant growth does not necessarily mean that different light levels has caused the difference in plant heights you observed between your front and back yards. Some other factor such as differences in soil composition or frequency differences in the watering of the two flower beds might be the prominent contributing factor.

When hypotheses are continuously supported when subjected to very many tests, may become part of a **scientific theory**. It is very important to note that non-scientists often use the word "theory" to mean "just a guess." However, in science, the word "theory" has a very different, very specific meaning: ***"a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses"*** (National Center for Science Education 2008).

In the following series of exercises, you will utilize various elements of science, as well as the laws of probability to help you decide on the possible identity of one or more mystery objects (from a set of 11 potential objects) in a container (the "Black Box") without opening the container first. In science, the term "black box" is often used to refer to something unknown.

Under Exercise 1.3a, you will use the senses available to you in formulating hypotheses (ideas) about the identity of the object(s) in the Black Box. To assist you in this endeavor, this unit also has another container, the "White Box," which you may open. The White Box contains a series of objects from which the mystery object(s) in the Black Box have been selected: a toothpick, crayon, paper clip, rubber ball, metal ball, cotton ball, rubber band, marble, penny, poker chip, and a cork. Depending on your grade level, you will be asked to either attempt to find the identity of one (grades 4-5) or two (grades 6-12) items in the Black Box. If it contains two objects, however, it will contain two *different* objects, and never two objects of the same type.

In Exercise 1.3b, you will compare your success in identifying the two objects through the use of the scientific principle of testing ideas versus the success you would have in merely guessing what is in the Black Box. You will apply the rules of mathematical probability in determining what number of guesses would be required to correctly guess the identity of the unknown item (s).

Exercises 1.3c & 1.3d are further extensions of the previous exercises, and are intended to provide you with an even more realistic understanding of how science works than the illustrations provided by Exercises 1.3a &b.

ONE RULE APPLIES THROUGH ALL OF THESE EXERCISES: NO PEEKING INTO THE BLACK BOX UNTIL YOU COMMIT YOUR HYPOTHESIS TO PAPER, ANNOUNCE IT TO YOUR CLASS, AND YOU ARE INSTRUCTED TO OPEN IT!

Exercise 1.3a.1: Black Box Trial 1: Exploration & Testing Ideas (*Grades 4-5*)

NOTE TO TEACHERS: Make sure each "Black Box 1.3a" tin has only *one* item inside it for grades 4-5, but *two different* items for grades 6-12.

- Divide into teams. (Six sets of this experiment are available). Each team should have a container labeled as the "White Box", a container labeled "Black Box 1.3a," and an empty clear plastic container. **NOTE: The Black Box container should not be opened during the course of this experiment.**
- Open the "White Box" container. Check to see that there are 11 unique items in this container. If not, contact your teacher for replacements. **DO NOT TOUCH OR OTHERWISE INTERACT WITH YOUR GROUP'S BLACK BOX AT THIS POINT!**
- Examine each of the 11 objects in the white box, paying particular attention to their geometric attributes (shapes). Note whether each object is spherical (ball-shaped), flat, rectangular, round, etc. Try to think of other characteristics that might help you determine the identity of the mystery item in the Black Box

without first opening it! How about the sound an object makes in the tin container (soft or loud, a thud or a clink, etc.), how heavy it feels in your hand relative to other objects etc. You may wish to make observations of the characteristics of specific items placed in the White Box one at a time to give you an idea on what you might observe in the Black Box later. If you do so, you can place all the other White Box items in the clear plastic container to keep them from rolling off your desk. Be creative in devising a testing plan! What characteristics will you examine and how will you do this?

- Make a table listing each of the 11 objects as rows in a table like the one shown below for comparing US coins. The column headings are characteristics or attributes that you have recorded for each coin type. For instance, a penny is round and flat (characteristic 1), coppery in color (characteristic 2) and the third largest of the coins listed (characteristic 3).

Item	**Characteristic 1 Shape**	**Characteristic 2 Color**	**Characteristic 3 Size (1 = largest)**	**Etc and so on**
Penny	Round, flat	Coppery	3	
Nickel	Round, flat	Silver	2	
Dime	Round, flat	Silver	4	
Quarter	Round, flat	Silver	1	

- Examine the table that you have constructed that lists the characteristics of each of the potential items from the White Box that could be in your Black Box. You have just used one element of science (exploration) to explain some aspect of the natural world (the identity of an object in your Black Box).
- Now take a moment to again think about the central focus of science which is to test ideas. You know that there are actually 11 different objects that could possibly be in the Black Box. Therefore, there are a total of 11 different ideas (hypotheses) that you can test!
- Make a list of all 11 possible hypotheses for this experiment, each in the form "There is a _______ in the Black Box."
- Beside each hypothesis, make one or more predictions as to what you might observe about the Black Box (again, without opening it!) if that hypothesis is correct, using some of the characteristics you used in the table you have constructed.
- For example, if the particular hypothesis is "There is a cotton ball in the Black Box," and the traits you used were the sound and perceived weight of the 11

objects from the White Box, a logical prediction might be "If there is a cotton ball in the Black Box, the Black Box will be very light, and not make a noise when shaken."

  - After you have made a list of all possible hypotheses and predictions based on the characteristics you used in constructing your table, it is time to put each of these hypotheses to the test!
  - Using the cotton ball example above, you could test your prediction by picking up the Black Box and shaking it. If the Black Box does not feel very heavy, and does not make a sound, that supports your initial hypothesis that a cotton ball is the unknown item within. However, be aware that there may be other hypotheses regarding the contents that would have similar predictions!
  - If when you picked up the Black Box, it felt heavy and made a clanging sound when shaken, this does not match your initial prediction. You must then revise your hypothesis. Using your table of attributes of each possible object, as well as your list of hypotheses and predictions, draw a line through each hypothesis whose predictions are not met by your tests on the Black Box. You should be able to eliminate several hypotheses in this way.

- Did you have more than one hypothesis that was still supported after your tests on the Black Box? If so, examine all the White Box items again, and see if you can come up with any other traits that might help you further narrow down the possible identity of the Black Box object without opening it yet.
- In the end, decide as a team, what the object within the Black Box may be and prepare your statement as to the evidence that you have gathered in support of this hypothesis. DO NOT OPEN THE BLACK BOX YET!
- After all teams have come to a decision on the identity of their mystery objects, your teacher will have each team tell the class what your conclusion is and how you came to arrive at that conclusion.
- Your team will then open your Black Box. Were you correct?
- One of you or your teacher should record on the board the number of teams that correctly identified the objects in their Black Boxes, as you will use this information in comparing the probability of obtaining a correct answer to a question posed through use of scientific practices versus simply guessing under **Exercise 1.3b1.**
- Go on to this latter exercise.

Exercise 1.3a.2: Black Box Trial 1: Exploration & Testing Ideas (*Grades 6-12*)

NOTE TO TEACHERS: Make sure that each "Black Box 1.3a" tin has TWO different items from the 11 possible items inside it when using this exercise for grades 6-12. Also check to see that the White tin has the following 11 unique items in it: a toothpick, crayon, paper clip, rubber ball, metal ball, cotton ball, rubber band, marble, penny, poker chip, and a cork. There are six sets of this exercise available.

- Split into small groups of students. All of the students within each 'team' formed will collaborate to determine which two mystery objects they have received.
- Each group should be given one tin labeled as the White Box, a second tin labeled "Black Box 1.3a", and one of the clear plastic containers (which can be used to keep White Box objects not in use from rolling off of desks/tables). **DO NOT TOUCH OR OTHERWISE INTERACT WITH YOUR GROUP'S BLACK BOX AT THIS POINT!**
- Refer back to the diagram in Figure 2 that illustrates the elements of science with respect to testing ideas.
- Examine the objects in the White Box, listing them on a sheet of paper or on the board at the front of the room so that you may consult the list as your investigation proceeds.
- As a group, you should consider how you will approach the problem scientifically, using the scientific element of exploration. For example you might choose to explore the characteristics (sounds, mass) of the Black Box itself and record these. Your hypothesis would be that the objects would have to have a particular sound, weight, and/or behavior relative to one another. Examples of alternative approaches include exploring the behavior of the 11 objects, individually, or in pairs in the White Box tin, and then making predictions about how the objects should sound etc.) if they were in the Black Box.
- If you need help in defining your approach, you can consult the steps described under the answers for Exercise 1.3a. However, you will learn more from devising the technique you apply to the problem yourselves.
- Write the testing procedures you plan to use on a sheet of paper.
- Start the process, remembering to keep in mind the central principle of testing ideas (Figure 2)!
- As you gain information through exploration, begin making a list of hypotheses and assumptions under each of the hypotheses as you progress.
- Record the steps you have taken throughout your investigation.

- Finally record what your team concludes is in the Black Box, **but do not open the Black Box yet!**
- When finished, each team should report the following information to the class:
    - the approach they have taken to the problem,
    - the hypotheses they constructed,
    - the steps they used to test their hypotheses,
    - revisions to hypotheses inspired by the testing process,
    - and finally, what two objects they feel are in the Black Box and why.
- Now the team should open the Black Box and check to see if they were correct.
- Tally the number of teams that correctly obtained the two items present in their Black Box versus the number of teams that failed to obtain the identity of both items on the board for the class to see.
- Calculate the proportion of teams that correctly identified the two unknown objects. If three of the six teams obtained the correct pair of items, your success would have been 3/6 =1/2 = 0.5 = 50%.
- Use this information in comparing the probability of obtaining a correct answer to a question posed through use of scientific practices versus simply guessing under the rules of probability in **Exercise 1.3b2.**
- Go on to this latter exercise.

Exercise 1.3b.1: Using Simple Probability (*Grades 4-5*)

Suppose that instead of using the exploration element of science to assist you in testing ideas, you just ***guessed*** which item was in your Black Box without interacting with it in any way. Would you have done as well? Probably not! The reason is that, although using the exploration element of science to inspire ways of testing the identity of the objects in the Black Box may not have *completely* determined which objects were in the Black Box, it helped you to narrow the list of possibilities. On the other hand, guessing involves chance. When we talk about the chance that a particular event will happen, we are talking about **probability**. Thus when we hear about the chance of rain, the chance of snow, or the chance that any particular weather event will happen, we are hearing about the *probability* of a particular weather condition occurring. We also hear about the chance of winning the lottery, which is really the *probability* that we will win, or how likely we are to win.

Making predictions about the likelihood of a certain event happening is a very important skill, and helps us in many areas of our lives. Aside from just being useful information about the weather and the lottery, understanding probability is very useful in studying health and disease, transportation safety, sports, and protecting the environment, just to name a few.

First, it is important to understand the distinction between two similar terms that are often (incorrectly) used interchangeably: probability and odds. The **probability** of a certain occurrence can be expressed in many ways, such as a fraction, a decimal, or a percentage, and represents the chances for that particular occurrence divided by the total chances of any occurrence. For example, imagine rolling a single die. If you wanted to know the probability of rolling an even number, this would be calculated as follows. An even number could be rolled 3 different ways (as a 2, 4, or 6). There are a total of six different results that could be rolled, however. So, the probability of rolling an even number would be equal to

$$\boldsymbol{Probability\ of\ rolling\ an\ even\ \#\ on\ die} = \text{"3 out of 6"} = \mathbf{3:6} = \frac{\mathbf{3}}{\mathbf{6}} = \frac{\mathbf{1}}{\mathbf{2}} = \mathbf{0.5} = \mathbf{50}\%$$

- Now choose a characteristic or attribute that one or more of the 11 items in the white box possesses. Find the probability of an object possessing that characteristic being in the Black Box.
- Express this probability in the five different forms it can be expressed as shown in the equality equation above.
- Working with your team, repeat this process with other attributes to find the probability of objects possessing a particular attribute of being present in the Black Box.
- Be sure to record these results in a table.

You have just determined the *simple probability* of objects with certain characteristics being in the Black Box!

You have probably heard people talk about **odds**. Odds are related to probability, but with a distinct difference. *Probability* compares how likely it is a certain event will happen compared to the total number of possibilities, while *odds* are the comparison of the number of favorable outcomes (what you are looking or hoping for) to the number of unfavorable outcomes (what you are not hoping or looking for). Going back to our example of rolling a die, the probability of rolling an even number is 3:6, because there are three possible even results out of the total six possible results.

On the other hand, the odds of rolling an even number are 3:3 because there are three possible even numbers that could be rolled (2, 4, & 6), and three possible results that are *not* even numbers (1, 3, & 5).

Now let's apply this knowledge to your Black Box problem.

- Find the *odds* of an object with a particular characteristic being in the Black Box.

Q1. What is the probability of spherical (ball-shaped) object being in the Black Box? Express this probability in the five different ways described above. Remember, all of these values mean exactly the same thing!

Q2. What are the **odds** of a spherical object being in the Black Box?

Q3. If you were to simply guess the identity of the object in your Black Box without using elements of science to guide your interaction with the Black Box, what would be the **probability** that you got the answer correct?

- Examine the proportion of groups that arrived at the correct identity of the objects in Black Box 1.3a, and compare this to the answer to the previous question.

It is very likely that the proportion of groups that got the correct answer is larger than the probability obtained by guessing alone. This is because, by using the elements of science to guide you in testing ideas, you were in effect narrowing down the list of possible objects in the Black Box, thus increasing the probability that you got the answer right!

Check your answers to these questions in the Answers section of this book, under Exercise 1.3b.1!

Exercise 1.3b.2: The Rules of Probability (*Grades 6-12*)

Suppose that instead of using elements of science to help you test ideas, you just guessed which items were in your tin without performing any experiments or observations. Would you have done as well? Probably not! The reason is that, although using elements of science may not have *completely* determined which objects were in your tin, it helped you to *narrow the list of possibilities*. Thus, it *increased the probability that your final choices would be correct*. In this exercise, we will examine the laws of probability, which will mathematically explain why applying scientific principles to the Black Box problem beats merely guessing the contents.

First, it is important to learn a bit of terminology involving probability. To every experiment, there corresponds a set of *possible outcomes*, called the **sample space** of the experiment. For example, the sample space of rolling a single die can be represented as follows: {1,2,3,4,5,6}, with each of the numbers in the brackets representing all of the possible results of the roll. A subset of the sample space is called an **event**. To be more specific, an event is a set that contains some (possibly all) of an experiment's outcomes. For example, the set $\boldsymbol{E} = \{\mathbf{2}, \mathbf{4}, \mathbf{6}\}$ is an event, representing rolling an even number on the die. Note that the order in which we list the elements in the set does not matter. This means that the sets $\{\mathbf{2}, \mathbf{4}, \mathbf{6}\}$ and $\{\mathbf{6}, \mathbf{2}, \mathbf{4}\}$ (as well as all possible orderings of 2, 4, and 6 in a set) are considered to be the same.

Events such as $\{\mathbf{2}\}$, which contain a *single element* are called **elementary events**. If two events contain none of the same elementary events, then they are said to be **mutually exclusive events**. For example, $\{\mathbf{2}\}$ and $\{\mathbf{4}, \mathbf{6}\}$ are mutually exclusive events.

Q4. Suppose that you roll a six sided die. Let $\boldsymbol{E}$ denote the event that you roll less than a five. Write down all of the elements that belong to the event $\boldsymbol{E}$.

Q5. Let $\boldsymbol{B}$ be the event that you roll $\mathbf{1}, \mathbf{4}$, or $\mathbf{6}$, that is, let $\boldsymbol{B} = \{\mathbf{1}, \mathbf{4}, \mathbf{6}\}$. Are $\boldsymbol{B}$ and $\boldsymbol{E}$ mutually exclusive? If not, which elementary events belong to both $\boldsymbol{B}$ and $\boldsymbol{E}$?

However, what is probability itself? The **probability** that any specific event occurs is a measure of the likelihood that the event will occur. The probability of a certain occurrence can be expressed in many ways, such as a fraction, a decimal, or a percentage, and represents the chances for that particular occurrence divided by the total chances of any occurrence. If $\boldsymbol{E}$ is an event, then we denote the probability that $\boldsymbol{E}$ occurs by $\boldsymbol{P}(\boldsymbol{E})$. Sometimes the probability that an event occurs can be determined through intuition. At other times it may be determined experimentally. There are three basic **axioms** (rules) of probability that are used to determine the probability that an event occurs. On the following page, you will find a list of these basic axioms, expressed in both a mathematical format, as well as explained in words. Understanding these basic axioms, as well as further rules that are extensions of these axioms will assist you in solving problems using probability.

Axioms of Probability

1) If $\boldsymbol{S}$ is the sample space of an experiment, then $\boldsymbol{P(S) = 1}$
2) If $\boldsymbol{E}$ is any event, then $\boldsymbol{0 \leq P(E) \leq 1}$
3) If $\boldsymbol{A}$ and $\boldsymbol{B}$ are mutually exclusive events, then $\boldsymbol{P(A\ or\ B) = P(A) + P(B)}$

Or, expressed verbally,

1) The sample space *S* of an experiment is the set of all possible outcomes. One of the outcomes in the sample space will definitely occur.
2) The likelihood of a particular event ranges from impossible to absolutely definite. (Probabilities are usually expressed as fractions, or more commonly, decimals, ranging from 0, or 0% likely, to 1, or multiplied by 100 for expression as percents as in 0 to100% likely.)
3) If an outcome can be one of two alternatives (but not both), the probability of either event occurring is equal to the sum of the likelihood of each event's occurrence.

A couple of very useful rules follow directly from the axioms of probability, which we will discuss below.

Rule 1:
When every outcome in a set of possible outcomes is equally likely to occur, the probability that a specific outcome occurs is equal to one divided by the number of possible outcomes.

For example, imagine rolling a single die. Since a fair die should have equal surface areas on each of its faces, obtaining any result should be equally likely. For example, the probability of rolling a 1 is the same as the probability of rolling a 2, a 3, a 4, a 5, or a 6. Since there are six possible outcomes, the probability of obtaining any of these results would thus be equal to 1/6 (which is approximately equal to 0.167, or 16.7%). In any case, the probability of an event is equal to the number of ways that the event could happen divided by the total possible results. For example, if you wanted to know the probability of rolling an even number on a fair die, this would be calculated as follows. An even number could be rolled 3 different ways (a 2, 4, or 6). There are a total of six different results that could be rolled, however. So, the probability of rolling an even number would be equal to

$$\textit{The probability of rolling an even \# on a die} = \frac{3}{6} = \frac{1}{2} = 0.5 = 50\%$$

This is an example of a **simple theoretical probability**, which again is the proportion of a particular possible outcome out of the total number of possible outcomes.

However, since your Black Box has two objects in it, there are separate probabilities for each object in your Black Box having a particular identity. However, when there are separate probabilities for different events, these probabilities can be combined into a single **compound probability**. For example, consider the outcome of rolling a single die and flipping a coin. The probability of obtaining an even number on the die would be equal to 1/2 (= 0.5 = 50%), and the chance of obtaining a result of tails on the coin would also be 1/2. However, what if we wanted to know the probability of obtaining an even number on the die *and* a result of tails on the coin? In order to calculate the compound probability of two events, first we should be aware of whether the events are **independent**. **Two events are independent if the occurrence of one event does not affect the probability that the other event will occur.** Our die and coin example is a good example of independent events, because the result of the die roll has no influence on the result of the coin flip. The contents of each group's Black Box 1.3a containers are also good examples of independent events. Since the pair of objects in each Black Box 1.3a is determined randomly, the contents of one group's Black Box 1.3a has no effect on the contents of any other group's Black Box 1.3a.

When two events are independent, the probability that both events occur is equal to the product of the probabilities that each event occurs.

- **In other words, if A and B are independent events, then $P(A\ and\ B) = P(A)P(B)$.**
- **Another way of saying this is that to find the compound probability of two independent events, multiply the probability of the first event by the probability of the second event.**
- **In fact, the converse is also true. If the probability that two events occur is equal to the product of the probabilities that each event occurs, then the events are independent.**
- **If $P(A\ and\ B) = P(A)P(B)$, then A and B are independent events.**

Dependent events, on the other hand, are events in which the outcome of one event does have an effect on the outcome of the second event. For example, imagine a bag that holds 8 pieces of candy: 3 green and 5 red. The probability of getting a red piece on the first draw is 5 out of 8, but with each consecutive draw, the probability of getting a certain color changes because the total number of pieces decreases as you continue to draw pieces out of the bag. The probability of getting a certain color *depends* on how many and what color candies have already been removed from the bag. To find the probability of dependent events, find the probability of the first event, then find the probability of the second event from which you have removed the first event. In the above bag of candy, the probability of choosing a red candy on the first draw is 5 out of 8, the probability of getting a green candy on the second draw *without returning the red candy to the bag* is 3 out of 7 because there are now only a total of 7 pieces in the bag. Multiply the two probabilities together to get a compound probability of 15 out of 56.

The probability of each object's identity in a single group's Black Box 1.3a is dependent on the identity of the other object. The probability of the first item being a crayon in the Black Box is equal to 1/11. But, because the two objects in your group's Black Box 1.3a are different, if the first object in your Black Box 1.3a is a crayon, the probability that the second object is a crayon is equal to zero. It has to be a different object. Likewise, if one object in the box is NOT a crayon, the probability of the other object being a crayon is equal to 1/10 (the second object can only be 1 of 10 objects, since it has to be different than the first).

- Now answer the following questions about independent/dependent events.

  Q6. Suppose two coins are tossed. Let ***A*** be the event that the first coin is heads, and ***B*** be the event that the second coin is heads. Are ***A*** and ***B*** independent?

  Q7. Suppose that two children attend the same daycare. Let ***A*** be the event that the first child catches a cold and ***B*** be the event that the second child catches a cold. Are the events ***A*** and ***B*** independent?

  We can use the ***counting principle*** to help us solve for the total possible outcomes of two events.

The Counting Principle

If there are x ways to perform one task, and y ways to perform a second task, then there are xy ways to perform both tasks.

Suppose for example that we flip two coins. There are 2 ways to flip the first coin (heads or tails) and 2 ways to flip the second coin, so there are $2 \times 2 = 4$ (possible outcomes when we flip both coins) ways to flip both coins.

In our Black Box, how many outcomes are possible? In this case, the possible outcomes are the possible pairs of objects that could be present in the Black Box. Since the pairs of objects in the Black Box are determined randomly, any pair of objects is equally likely. For example, the probability that the Black Box contains a marble and a cork (or any other pair of objects) is equal to one divided by the number of possible pairs.

What would be the probability of correctly guessing that the Black Box contains a marble and a cork? To answer this, we first need to count the number of possible pairs. We'll start by counting the number of ways there are to form a pair.

In our case of 11 objects, there are eleven ways to choose the first object, but only ten unique ways to add the second member of the pair, since each Black Box tin will contain two *different* objects. Therefore, according to the counting principle, there 11×10, or 110 ways to form a pair.

- Assume that instead of using elements of science to determine which pair of objects is in your Black Box, you randomly choose a pair that contains two of the eleven possible objects and then guess that this is the pair in your Black Box without interacting with it in any way. Since you choose the pair at random, you are equally likely to choose any pair. This means that you are just as likely to choose a toothpick and a cotton ball as you are to choose a marble and a cork.
- So, what is the probability that you choose a marble and a cork? The answer to this question depends on the Rule 1 of probability.
- To test your understanding of Rule 1 and the Counting Principle, answer the following two questions:

Q8. Suppose that you have a marble, a metal ball, and a penny. Imagine that you form a pair by choosing two objects from this set. How many ways can you form a pair?

Q9. How many *distinct* pairs can be formed from the three items above?

- Check your answers to these questions in the Answers section of this book, under Exercise 1.3b.2.

Although there are 110 different ways to form a pair from the set of eleven objects present in the White Box in our experiment, there are actually only 55 different pairs. This is because in the scenario we described under **Q9** above, there are two ways to form every pair. For example, we could form the pair with a metal ball and a rubber ball by choosing the metal ball and then the rubber ball, or by choosing the rubber ball and then the metal ball. Thus, it follows that there are half as many pairs as there are ways to form a pair (110/2 = 55).

Now we can figure out the probability of getting the identity of both objects in the Black Box correct by guessing alone, without using any elements of science. Since there are 55 different pairs of the 11 objects in the White Box, and you are equally likely to choose each pair, the probability that you choose a marble and a cork is $\frac{1}{55}$. That is, you make approximately 2 correct guesses for every 100 guesses you make. Thus, you can see that the probability of getting the identity of your mystery objects correct by guessing alone is very low!

- Compare this probability to the proportion of Black Box pairs your teams correctly identified.
- Now ponder the following question: What is the probability that you choose a pair that has a penny?

In order to answer to this question, remember our definition of an event. An ***event*** is a set of outcomes. Here the outcomes are pairs of objects, and the event of interest is a set of pairs that have pennies. Any pair that has a penny is in this event.

Q10. How many pairs in our Black Box experiment are in an event that has a penny?

- The answer to **Q10** depends on another basic rule of probability shown below (Rule 2). Apply this rule and check your answer in the Answers section under Exercise 1.3b.2.

Rule 2:
When every outcome in a set of possible outcomes is equally likely to occur, the probability that a specific event occurs is equal to the number of outcomes in the event divided by the number of possible outcomes.

- Test your understanding of probability theory by tackling the following related questions.

  Q11. What is the probability that your Black Box has a pair consisting of a penny or a marble, but not both a marble and a penny?

  Q12. What is the probability that, by guessing alone, you correctly guess the identity of one (but not both) of the objects in your Black Box?

Combinations, Permutations, & Ways of Selecting Objects

In the previous exercise and questions, it was explained that there are 110 different ways to **form** a pair of objects in the Black Box. This is because you know that there are no two identical objects in the Black Box. Thus, though there may be 11 choices for the first item placed in the Black Box, that leaves only 10 choices for the second item, and thus there are 110 ($11 \times 10 = 110$) different **ways** in which two objects could have been placed in the Black Box. However, the question of interest is what two objects are in the Black Box, and not the order in which those objects were placed into the Black Box (which you would not be able to determine). For example, you may think that you have a marble and a penny in your Black Box. However, this pair of items could have been constructed in two ways. Your teacher could have placed the penny in first and then the marble, or the marble first and then the penny. Either way still results in the same pair of objects, so the number of **possible pairs** of objects is only half the number of the number of **ways in which pairs could be constructed**.

Another way to handle similar tricky probability problems like these would be to think about the concepts of **combinations** and **permutations**. Both combinations and permutations involve groups of objects, numbers, etc. However, the major difference between the two is whether or not the **order** of the objects/numbers is important. In this exercise, you will learn a little more about both combinations and permutations, in cases where repetition is/is not allowed, and some formulas related to each scenario that can be used to make probability problems easier.

A **combination** is a group of objects/numbers in which order ***is not*** important, and a **permutation** is a group of objects/numbers in which order ***is*** important. For a fun (and tasty) example, let's consider a trip to an ice cream shop. In our hypothetical ice cream shop, 5 flavors of ice cream are available: chocolate, vanilla, strawberry, banana, and cherry. This particular ice cream shop only offers two options: milkshakes and cones, both of which come in sizes ranging from one to five scoops.

A milkshake at this shop would be the equivalent of a **combination**, since the order in which flavors are added to the blender wouldn't matter, since they all get blended together.

A cone in this shop, however, is an example of a **permutation**, where order *does* matter, since you would be eating the scoops of different flavors in a particular order from top to bottom (and you might like to eat a certain flavor first or last!).

- Take a moment and see if you can write down all the different flavor **combinations** for a three-scoop shake, if you do not use more than one scoop of any flavor.

You should have determined that there are a total of 10 different three-scoop shakes (combinations) that you can get if you do not use more than one scoop of any flavor, as listed below:

- vanilla, chocolate, strawberry
- vanilla, chocolate, banana
- vanilla, chocolate, cherry
- vanilla, strawberry, banana
- vanilla, strawberry, cherry
- vanilla, banana, cherry
- chocolate, strawberry, banana
- chocolate, strawberry, cherry
- chocolate, banana, cherry
- strawberry, banana, cherry

You might think that it would be very difficult to figure out how many different shakes or cones of a particular size you would be able to get at this shop if they added a lot more flavors, or expanded the maximum size (number of scoops) allowable in a shake or on a cone, particularly if you also consider whether or not duplicate scoops of flavors are involved. However, there are mathematical formulas that can help you find these answers. Each of these formulas involves two variables: the number of objects from which a choice can be made (***n***), and the number of choices that are made (***r***).

Three of these formulas also involve the use of **factorials**. A **factorial** is a particular mathematical function of positive integers (whole numbers) ***which is equal to the product of all integers less than or equal to the integer in question***. The factorial function is denoted by an exclamation point after a particular integer. For example:

$$\text{"n factorial"} = \boldsymbol{n}! = \boldsymbol{n} \times (\boldsymbol{n}-\mathbf{1}) \times (\boldsymbol{n}-\mathbf{2}) \ldots \times \mathbf{3} \times \mathbf{2} \times \mathbf{1}$$

Factorials for all positive integers are thus calculated in exactly the same way. The only example that may (initially) seem a little strange is the convention that the factorial of zero (**0!**) is considered to be equal to 1. This may be a little more clear if you think about it in a way such that there is exactly one way of arranging zero objects: an empty set.

Where order does **not** matter (like the shakes in our ice cream shop), the following formulas can be used to determine the number of possible **combinations**:

The number of ways to select ***r*** objects from a set of ***n*** distinct objects (when the number of selected objects is less than the total number of objects, or expressed mathematically, $\boldsymbol{n} \geq \boldsymbol{r}$), can be expressed as follows:

$$\textit{\textbf{Number of combinations (repetition NOT allowed)}} = \frac{\boldsymbol{n}!}{(\boldsymbol{n}-\boldsymbol{r})!\,(\boldsymbol{r}!)}$$

The following equation can be used to calculate the number of ways to select ***r*** objects from ***n*** types of objects (when there are at least ***r*** objects of each type available):

$$\textit{\textbf{Number of combinations (repetition IS allowed)}} = \frac{(\boldsymbol{n}+\boldsymbol{r}-\mathbf{1})!}{\boldsymbol{r}!\,(\boldsymbol{n}-\mathbf{1})!}$$

Where order **does** matter (like the cones in our ice cream shop), the following formulas can be used to determine the number of possible **permutations**.

The number of ways, when order is important, to select ***r*** objects from a set of ***n*** distinct objects (when the number of selected objects is less than the total number of objects, or expressed mathematically, $n \geq r$), can be expressed as follows:

$$\textit{Number of permutations (repetition NOT allowed)} = \frac{n!}{(n-r)!}$$

And finally, the number of ways, when order is important and repetition is allowed, to select ***r*** choices from ***n*** objects, and when there are at least ***r*** objects of each type available can be calculated as follows:

$$\textit{Number of permutations (repetition IS allowed)} = n^r$$

Using the ice cream shop example in each of these equations, ***n*** is the number of possible flavor choices, and ***r*** is the number of scoops in our milkshake or on our cone. Therefore, going back to our "three scoop, no flavor duplication" shake example, we can substitute those values into the appropriate **combination** equation as follows (with 5 flavors, taken 3 at a time):

$$\frac{n!}{(n-r)!\,(r!)} = \frac{5!}{(5-3)!\,(3!)} = \frac{5!}{(2!)(3!)} = \frac{5 \times 4 \times 3 \times 2 \times 1}{(2 \times 1)(3 \times 2 \times 1)} = \frac{120}{(2)(6)} = \frac{120}{12} = 10$$

- Now answer the following questions:

Q13. Fill in the following table regarding the number of possible shakes and cones in our hypothetical ice cream shop:

# of Scoops	# of possible shakes (no flavor duplication)	# of possible shakes (duplication allowed)	# of possible cones (no flavor duplication)	# of possible cones (duplication allowed)
1				
2				
3				
4				
5				

Q14. Regarding the Black Box experiment, are your hypotheses more related to combinations or permutations? Why?

Q15. Using what you now know about combinations and permutations, and the fact that there is NO duplication of objects in the Black Box, calculate the number of different pairs of 11 objects from the White Box that could be placed into a Black Box.

Q16. Since the pairs of items placed into a Black Box are determined at random, what is the probability that there is a marble and a cork in any given Black Box?

Q17. What if you were given a Black Box and told that there were three items in the box (with the same restriction of no identical items). What would be the probability of correctly guessing *all three* items in the box without using the any elements of science, and without any contact with the Black Box whatsoever?

Exercise 1.3c: Black Box Experiment Trial 2: Community Feedback & Analysis (*Grades 6-12*)

Science can never *absolutely* verify something as true. Because you were able to open the Black Box at the end of your investigation in Exercise 1.3a and actually learn what items were in the tin, you obtained a distorted view of the scientific process. This exercise corrects that misconception. In this exercise, all teams will be given a tin labeled "Black Box 1.3c," each of which contains identical pairs of two different objects from the 11 possible items in the White Box. Individual teams should follow the same procedure as that described under Trial 1 (Exercise 1.3a). You will follow the same procedures as before. At the end of this experiment, your teacher will lead a discussion to see if a consensus can be reached amongst all teams as to what two items are present in Black Box 1.3c.

This exercise highlights the importance of another element of science: collaboration and sharing of information within the scientific community, which may not only increase the overall knowledge base, but also help reduce the influence of bias in interpreting one's results (See Fig. 1).

- Each team should obtain a White Box with the 11 potential items present, a clear plastic container and a tin labeled "Black Box 1.3c". These tins will have a screw on them that prevents removal of the lid.
- You may use the data you gathered from Trial 1 in this effort so that you need not start from scratch. In the end, however, be prepared to defend your team's decision with data.

- Complete an initial tally on the board at the front of the room of the team decisions as to what the two items are in the tin.
- Complete some simple statistics on your class data, and/or make a bar graph (e.g., proportions of teams that had the same respective single and pair of items (see tables below for an example of how to present these results.

Team Name	Pair of Items	% teams
Solutions	Toothpick marble marble toothpick	20%
Sweet Tea	poker chip marble marble poker chip	20%
Avatar	poker chip rubber band rubber band poker chip	20%
No Name	poker chip cotton ball cotton ball poker chip	20%
Complex Numbers	Rubber band marble Marble rubber band	20%
Guess	2/110 =1/55	1/55 = 1.8%

Particular item one of the two present	% teams
Toothpick	20%
marble	60%
poker chip	60%
rubber band	40%
cotton ball	20%

- If there was no general agreement as to what one or both of the items were in the tins, then each team should present its case for the items they thought were present.
- The teams might want to use techniques others report for themselves in a second go at determining what is in the Black Boxes. In the end, add another column on the board and census the teams again for their decisions.
- Has the community discussion and/or additional examination using new approaches changed the proportion of teams that feel a particular pair of items is in the black box, that a particular item is present? **It is important to understand that in science, no votes are taken to decide what is true.** Dissenting views are not only welcome, but drive further assessment.
- Keep a copy of the class results in preparation for Trial 3.

Exercise 1.3d: Black Box Experiment Trial 3: Outcomes & Benefits (*Grades 6-12*)

While science cannot *completely* verify something as true, the interaction of the various elements of science often leads to new techniques, tools, and approaches, allowing scientists to have greater confidence in their assessment of questions. You will experience this firsthand in this final exercise.

- Find the container which includes 6 magnets, 6 spring scales, and 6 hair nets (which are used to suspend the White/Black Boxes from the hooks on the spring scales). **NOTE:** Some newer copies of this unit may contain digital scales and calibration masses instead of spring scales and hair nets.
- Each team should take one of each of these items. These represent new techniques or technologies that were previously unavailable in your earlier experimentation with the items in Black Box 1.3c under Exercise 1.3c. The provision of new tools to you in this exercise parallels the development of new techniques or tools in many scientific fields. These new approaches may have been developed based on inspiration from other scientific work or even result from arguments made by scientists with dissenting opinions concerning the consensus view of prior testing of an idea.
- You can now use these tools to assist you in assessing the properties of the items in the White Box, as well as the unopenable Black Box 1.3c.
- Add your results from the use of these tools to a new column in the tables you have made on the board at the front of the room.
- Has the additional examination of the problem using the new tools available to you changed the proportion of teams that feel a particular pair of items or a particular item is present in the Black Box 1.3c?

  NOTE: While you are moving towards the truth, one cannot truly verify what is in Black Box 1.3c, as you are not able to open it and look inside. If you could, it would no longer be a black box, but a white box!

Exercise 2: Chemical Olfaction (Smell)

Almost all animals use the chemical senses, taste and smell, to some extent. The chemical senses involve the detection of molecules. Different molecules have different structures, and can thus be perceived as different odors and/or tastes. However, just as related frogs have similar songs, materials that are composed of similar molecules have similar smells and tastes. To aquatic and burrowing animals, the chemical senses are the prominent one. Birds primarily rely on their senses of vision and hearing, with their sense of smell previously thought to be less important than in many mammals. However, recent research suggests that the relative importance of the sense of smell varies widely among birds, though overall might be much more important to birds than was previously thought.

Our chemical sense of olfaction is crude compared to that of man's best friend, the dog. For example, dogs have approximately 25-60 times (depending on breed) the number of scent receptors than those possessed by humans. On **scent receptor cells**, there are tiny hair-like structures called **cilia**, which help gather/trap molecules that the brain interprets as scents. Not only do dogs have a greater number of scent receptors, but their scent receptors also have more cilia: as many as five times the number of cilia found on human olfactory receptor cells. Additionally, the percentage of the brain that is devoted to analyzing scents is 40 times greater in dogs than in humans. In general, it has been estimated that dogs' olfactory abilities are 1,000-10,000 times greater than those of humans.

The sense of smell itself has a wide variety of uses. It is important in finding food, avoiding dangerous environments, and even in social communication between or among individuals. In social communication, individuals produce odors called **pheromones** that elicit responses in other individuals of the same species (and often other species, as well). Some pheromones, for example attract other individuals of the same species, while other chemical signals tell others to stay away. For example, male wolves, foxes, and dogs mark their territories with urine, which repels other males. Some animals also release chemical signals when they are frightened, and this warns other individuals to seek cover or run away. The following two exercises explore the sense of smell using the human nose.

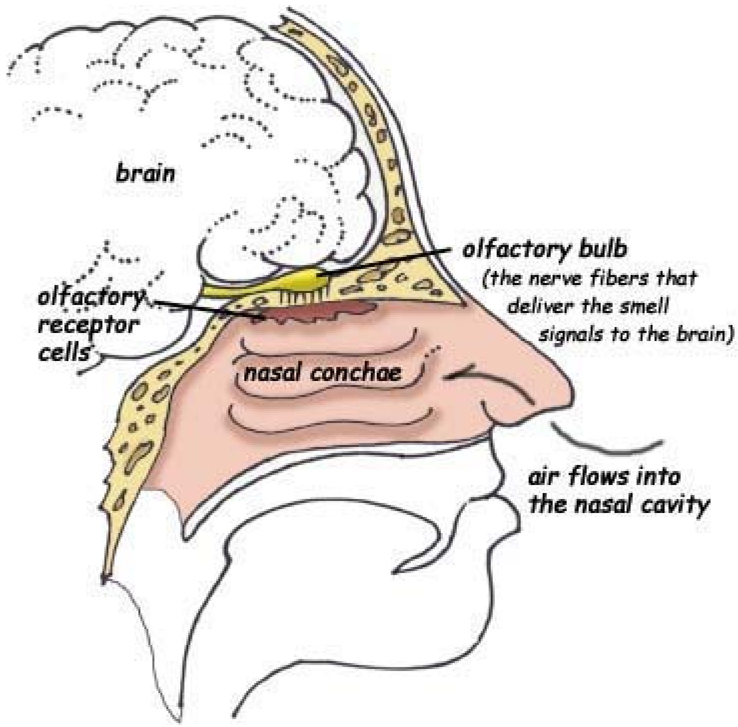


Diagram of the human olfactory system. Amsel, Sheri. "Special Senses." Smell. Exploring Nature Educational Resource. © 2005 - 2012. February 23, 2012. http://exploringnature.org/db/detail.php?dbID=25&detID=49

The Basics of Vertebrate Olfaction:

1. **Volatile** substances (substances that easily evaporate) release molecules, known as **odorants**, into the air. The amount of odorants released by volatile substances is affected by temperature and humidity, with greater numbers of odorant molecules being released at greater temperatures.
2. When an air-breathing vertebrate inhales, odorant molecules are drawn into the nostrils, where they encounter the **olfactory epithelium**. **Mucus**, composed of water and proteins, within the nasal cavity also helps dissolve these molecules, forming a solution of mucus and odorant molecules.
3. The odorant molecules then bind to receptors on the **cilia**, or hairlike structures on **olfactory neurons**. Two major hypotheses regarding the binding of odorant molecules to receptors propose that molecules bind to receptors base on either the molecule's shape, or perhaps the infrared vibrational frequency of the molecule, with different receptors being specialized for particular molecular shapes or vibrational frequencies. There are approximately 400 different types of scent receptors in humans, each of which are stimulated by different types of molecules.

4. Binding of an odorant molecule to a scent receptor on a cilium causes the receptor to transmit this information to the olfactory bulbs at the front of the brain. The olfactory bulbs then transmit this information to other regions of the brain for further processing and interpretation.

   NOTE: Different "scents" are not always (or even usually) composed of just one type of molecule. Different substances often release more than one type of volatile odorant molecules in varying concentrations. Therefore, animals can detect many more different "scents" than they have types of olfactory receptors, based on which kinds and relative numbers of olfactory receptors that are stimulated by binding with odorant molecules.

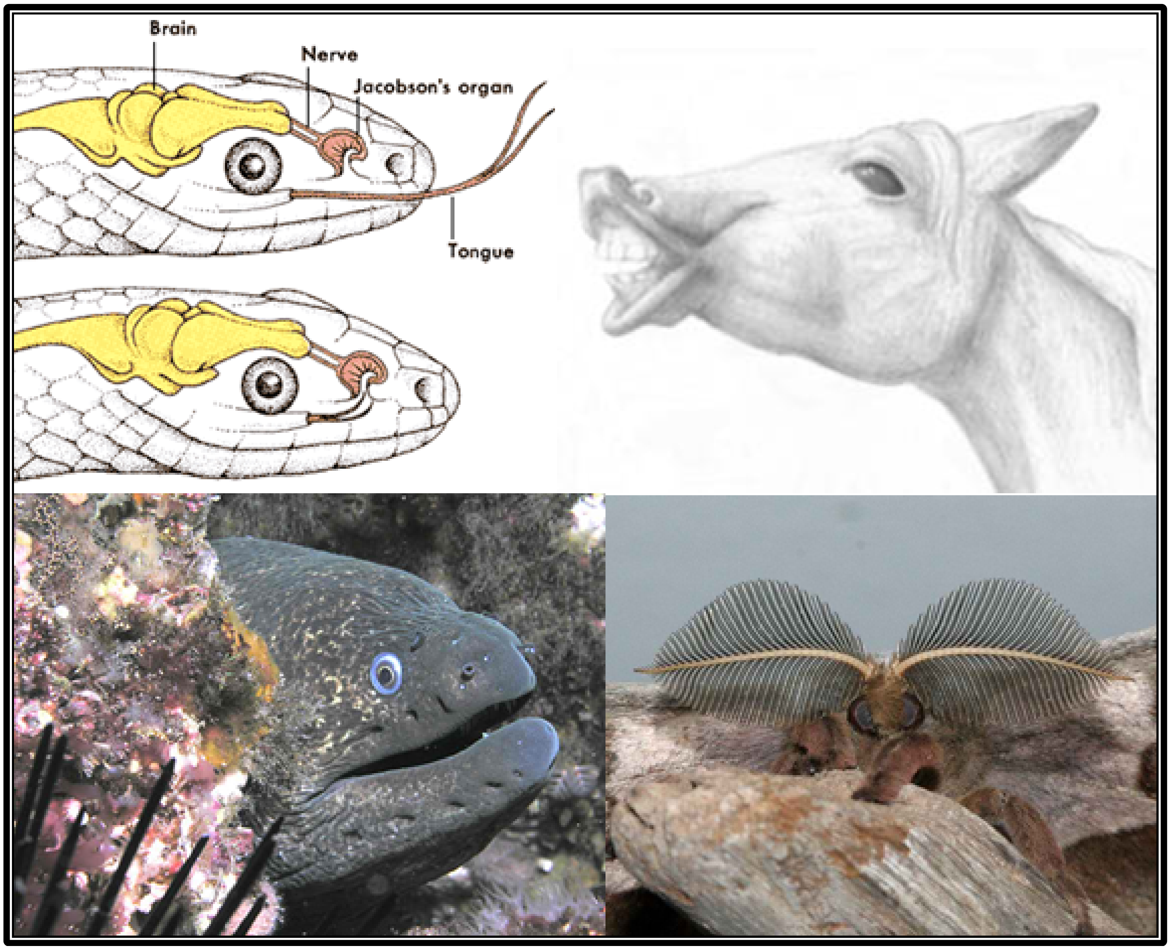
FUN FACTS

Snakes and lizards also use their tongues as olfactory organs. When a snake or lizard flicks its tongue in and out, it is actually using its tongue to pick up odorant molecules, which are transferred to the **Jacobson's organ** in the roof of the mouth. The forked tongues of all snakes and many lizards help these reptiles determine the direction of prey or predators.

Many other animals also have a Jacobson's organ, but it is not well-developed or used in certain animal groups. Some mammals in which the organ is still fairly functional (such as cats, horses, buffalo, giraffes, goats, and llamas) will often open their mouths when smelling the air (known as the **flehmen response**), in order to also bring odorant molecules to their Jacobson's organ to assist in detection of various scents.

Fish have openings on their snouts called **nares** (which is also a term used for other vertebrate nostrils), which connect the rest of their olfactory system to the external environment, and allow them to detect chemicals in the water. However, these nares do not connect with the mouth or pharynx (throat) as nostrils do in vertebrates, and these openings are not involved in breathing in fish.

Insects and other invertebrates typically have large concentrations of olfactory receptors on their antennae (if present), but may also have olfactory receptors in other locations, such as on their mouthparts, and even on their reproductive organs!



Upper left: Illustration of the Jacobson's (vomeronasal) organ in snakes. **Upper right:** Flehmen response in a horse. **Lower left:** California moray eel showing conspicuous nares (credit: Clark Anderson/AquaImages). **Lower right:** Male Polyphemus moth showing off his antennae, loaded with olfactory receptors (credit: Megan McCarty).

Exercise 2.1: How Good is Your Nose? (*Grades K-12*)

How good is your nose? In this exercise, you will be exposed to a series of odors, and will be asked to identify them without seeing the source of the smell. The odors are present in two levels of difficulty: coarse level discrimination and fine level discrimination.

Exercise 2.1a: Coarse Level Discrimination (*Grades K-12*)

Instructions:

- Locate the box labeled "Chemical Olfaction".

- Take out the 6 jars with blue stickers (and which are numbered B1-B6), and set them upright on a table. Do not open the jars.
  NOTE TO TEACHERS: This exercise can be completed in one of two ways, as outlined below.

  Method 1:
- On a piece of paper, make a list, numbered B1-B6.
- Your teacher will take the lid off of one jar at a time, and pass each jar around the room, allowing each student to smell the odor. **Do not remove the cardboard cover and/or cotton ball in the jar, and do not to share your thoughts on the source of the smell with your classmates!**
- Note the number on the jar, and on your list, write down one or more guesses at the source of the odor in the jar beside the number corresponding to the number on the jar.

  Method 2:
- Six different stations should be set up at different points in the room, with a different "blue" jar, at each station.
- On a piece of paper, make a list, numbered B1-B6.
- In an orderly fashion, visit each of the stations, and remove the lid from the jar at the station. Smell the odor inside the jar. **Do not remove the cardboard cover and/or cotton ball in the jar, and do not to share your thoughts on the source of the smell with your classmates!**
- Note the number on the jar, and on your list, write down a guess at the source of the odor in the jar beside the number corresponding to the number on the jar.

- After smelling the six odors in the blue jars and recording ideas for the sources of the odors (using either Method 1 or Method 2 above), your teacher will make a list of suggested possible sources for each of the six odors (B1 to B6) on the board. At this point, you may be given the opportunity to smell each jar again.
- For each jar, your teacher will determine the number of students (by show of hands) that chose each of the suggested odor sources for each jar.
- Now you should construct a bar graph for each jar, B1 through B6, indicating the number of students who chose each of the suggested sources.

  Bar graphs are useful tools for us to compare sets of information within a certain category. Before you construct your graph, your teacher will provide you with some examples of bar graphs and explain the different parts of the graphs. You will then decide what your **horizontal** and **vertical axes** will represent, as well as the **scale** you will use. Your scale will depend on the **range** of your data. The *range is the difference between the smallest number and largest number* in your data. It will be very important for you to be as neat and accurate as possible so your graph will be easy for someone else to read.

- Be sure to label both axes so the reader knows what they represent. You should also include a title for your graph. Your title should be a very brief explanation of what your graph describes. A graph is a visual explanation of a set of data, so its purpose needs to be clear to anyone looking at the graph.
- Your teacher will now provide you with another list of sources of the odors. However, this time, the list will only be a list of the actual sources of the odors for all of the blue jars.
- Repeat the exercise above, and for each jar, choose one of the possible options for the source of the odor.
- Now make a second graph indicating the possible sources of the odors described in the list, and the number of students selecting those sources correctly.
- Compare the information in your graphs. How are they similar? How are they different? What do you think influenced any similarities or differences?
- As a class, discuss the following questions. Did you do better choosing among the given list of odors or choosing an odor without the list of possible odor sources? In what way did having a list of potential odor sources influence your choices?

Exercise 2.1b: Fine Level Discrimination (*Grades K-12*)

The procedure for this exercise is identical to the procedure for the previous exercise, except using the "red" jars (numbered R1-R6) in place of the blue jars. These jars, however, have much more similar odors than the blue jars, with the source of the odor in each jar having a fruit scent. How many of the various fruit scents can you correctly identify?

Instructions:

- After smelling the six odors in the red jars and recording ideas for the sources of the odors, your teacher will make a list of suggested types of fruit for each of the six jars (R1 to R6) on the board.
- For each jar, your teacher will determine the number of students (by show of hands) that chose each of the suggested odor sources for each jar.

- Now you should construct a bar graph for each jar,R1 through R6, indicating the number of students who chose each of the suggested sources.
- Your teacher will now provide you with another list of fruits representing the scents in the jars. However, this time, the list will only be a list of the actual sources of the odors for all of the red jars.
- Repeat the exercise above, and for each jar, choose one of the possible fruit scents for each jar.
- Now make a second graph indicating the possible fruit scent described in the list, and the number of students selecting those sources correctly.
- Compare the information in your graphs, and think about the following questions: How are they similar? How are they different? What do you think influenced any similarities or differences? Which graph indicates more success in choosing the correct fruits? What do you think influenced the more successful identifications?

Exercise 2.2: Find that Flower I (*Grades K-12*)

Insects and flowers have a close tie to one another. Because flowers are stationary, many rely on insects for **pollination**. In insect pollination, insects carry pollen from the anther (male part) of one plant to the carpel (female part) of another, permitting the plants to produce fertile seeds. In return, plants often produce nectar to attract and feed the insects that conduct this delivery function for them. Insects have sensory organs to locate flowers, they have wings to get them to flowers that might be widely spaced, and they remember nectar rewards. Thus a given insect tends to focus on the same species of flower in a foraging bout, and this increases the chance that flowers will successfully produce seed sets.

It is actually very important to the plants that an insect visits only flowers of the same species when it is foraging from one plant to another, or all the nectar and pollen the individual plants have produced would go to waste. Thus different insects are attracted to the characteristic odors particular plant types produce. This exercise is a class activity that explores the flower selection process (and the relative importance of olfactory senses) of three insect types: a bee, a fly, and a butterfly.

Instructions:

- In the "Chemical Olfaction" box, find the three green jars (labeled "bee," "fly," and "butterfly"), a blindfold and a set of deely-boppers (a headband with wiggly antennae).

- The class should line up in two columns of individuals facing one another with sufficient space between the columns for an insect (member of the class) to walk through.
- Find a volunteer to serve as a foraging bee. The bee should place the deely-boppers on her/his head, as well as the blindfold.
- The teacher should find the "bee" jar, and identify a student in one of the columns that will serve as the target flower. Be careful not to reveal where this target flower is to the blindfolded individual.
- The "target flower" student should open the "bee" jar, and hold the jar out in front of his or her body at neck height.
- The blindfolded "bee" should now walk down the space between the two columns of students, and attempt to find the target flower by the scent it emits.
- Optionally, the above procedure can be repeated, with different students taking turns acting as the bee and target flower.
- The "bee" jar should then be closed, and returned to the "Chemical Olfaction" box.
- Repeat the above steps, first with the fly and then with the butterfly roles and scents.
- After conducting each of these simulations, have each of the students that played insect roles share with the class their relative experiences in their attempts at finding the target flower, then read about the preferences of these insect groups in the answer section at the end of this workbook.

Exercise 3: Vision

Touch and smell provide important information to animals about their environments and the activities of other animals in them. However, these senses are limited to simple messages. In the more complex animals, two vibrational senses, sight and hearing, are utilized prominently in communication among individuals and both in detecting prey and avoiding predators. Most animals are sensitive to light in one manner or another, and vision involves the perception and processing of stimuli in the form of light. Visible light is actually a narrow band of electromagnetic radiation of very short wavelengths. Electromagnetic radiation is a form of energy that is the result of interactions between electric and magnetic fields generated by the motion of charged particles (such as electrons), and includes all different types of waves, such as the radio waves that transmit your favorite songs, microwave energy you might use to cook food, X-rays, visible and ultraviolet light, as well as others.

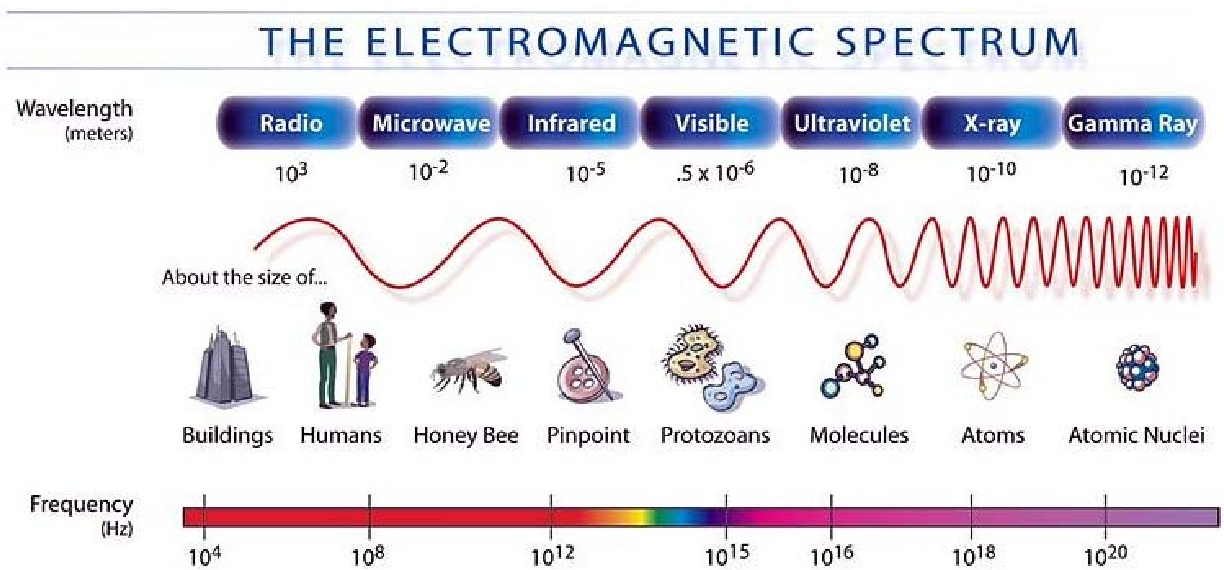


Figure 1. Illustration of the magnetic spectrum. The narrow band of rainbow colors (red through violet) near the middle of the spectrum represents the spectrum of visible light.

In this series of exercises, you will explore the function of vision in foraging, the avoidance of predation, and in social communication.

The Basics of Vision in Humans

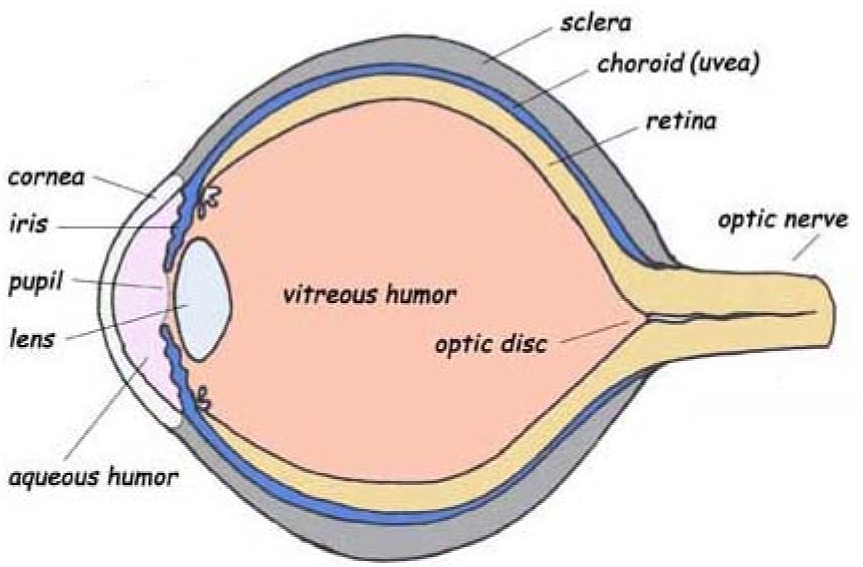


Figure 2. Anatomy of the human eye. Modified from Amsel, Sheri. "Special Senses." Sight. Exploring Nature Educational Resource. © 2005 - 2012. April 11, 2012. http://exploringnature.org/db/detail.php?dbID=25&detID=50

1. Light reflected from objects passes through the **cornea**, a clear layer of the **sclera**, which is the tough outer layer of the eye.
2. Light that enters the cornea is **refracted** (bent), and then passes through the **aqueous humor**, a watery liquid, before finally passing through the **pupil**, which is a hole that allows light to enter the interior of the eye. The **iris**, or colored part of the eye, is composed of mostly smooth muscle that expands and contracts to adjust the amount of light entering the eye.
3. After entering the eye at the pupil, light then passes through the **lens**, which helps to further focus the light passing into the eye, directing it through the **vitreous humor**, and onto the **retina**, or the inner lining of the eye that is involved with sensing light.
4. The **uvea**, which contains blood vessels that supply nutrients to and conduct gas exchange within the tissues of the eye, is very dark in color, thus reducing further reflection of light within the eye, much as the black interior of a camera. This helps improve the contrast of images projected onto the retina.
5. Due to the nature of the refraction of light through the cornea and lens, the image that is projected onto the retina is actually projected upside down.

6. The retina contains special types of cells that are involved in the detection and processing of visual stimuli. There are two varieties of these cells, each of which is named based on their shape. See Figure 3 below.

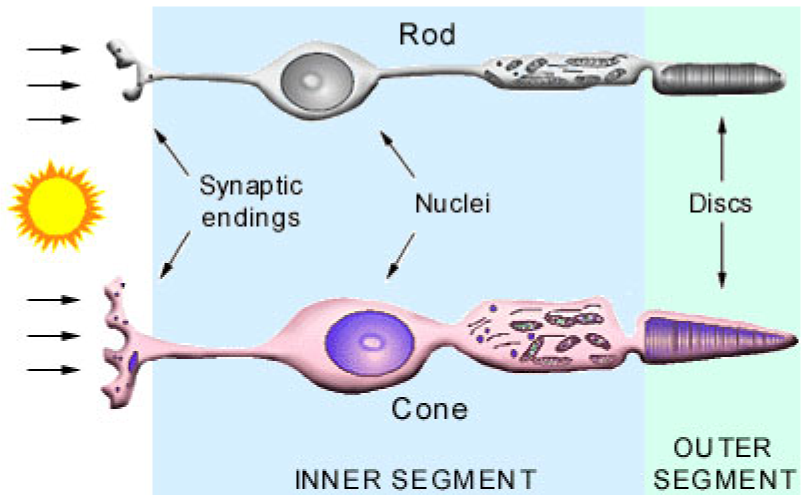


Figure 3. Comparison of rods and cones in the human eye. From ASU Ask A Biologist, "Rods and Cones". http://askabiologist.asu.edu/rods-and-cones

Rods are primarily involved in vision in low-light conditions, and distinguishing the basic shapes of objects, and **cones** are primarily devoted to color vision and detail. In humans and closely related primates, as well as in most marsupials, cones also come in three different types, with each of the three types being most sensitive to a particular color or range of wavelengths of light: red, green, or blue. Each of these types of cones can detect a range of wavelengths of light, but are most sensitive to the wavelengths of light corresponding to those particular colors. You might be wondering how or why we see *many* colors, when we only have three types of cones. This is because even though each of the three types of cones (red, green, and blue) is *most* sensitive to wavelengths of light of their respective colors, they can still be stimulated by other wavelengths. Our brains process the combinations of different levels of stimulation to each of these types of cones as different colors.

The outer segments of both rods and cones contain chemicals that are **photosensitive** (react to light). In rods, the primary photosensitive chemical is known as **rhodopsin**, while the cones' photosensitive chemicals are **color**

pigments. Incidentally, rhodopsin, which is important in detecting light in dim conditions (though not involved with color vision), is derived from vitamin A. Foods rich in vitamin A include carrots, sweet potatoes, dark leafy greens, apricots, and cantaloupe. Getting enough vitamin A is important for good vision, as vitamin A deficiency can lead to night blindness. This is one of many good reasons to eat lots of fruits and veggies!

FUN FACT: Color vision varies substantially in the animal kingdom! See the information below for some interesting examples!

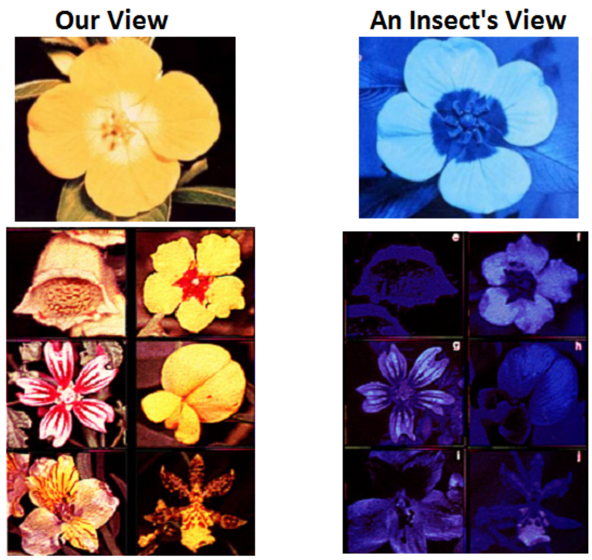
- Most mammals, with the exception of humans and closely related primates, have only two types of cone cells, and are thus color-blind to some degree.
- In New World monkeys, most males only have two types of cones, while many females have three types of cones. Exceptions include owl monkeys, which only have a single type of cone, and howler monkeys, which all have three types of cones.
- Pinnipeds (seals, walruses, and their relatives) and cetaceans (marine mammals including whales and dolphins) only have one type of cone.
- Fish and birds have a fourth type of cone that can detect other wavelengths of light, sometimes including ultraviolet light.
- Many insects, including honeybees, have three types of cone cells, for green, blue, and ultraviolet light.

7. When light strikes rods and cones, the photosensitive chemicals in these cells undergo reactions that generate electrical impulses, which are eventually transmitted to the **optic nerve**.
8. These electrical impulses are passed along the optic nerve to the brain, where they are interpreted in the **visual cortex**, which nearly instantaneously inverts the inverted image from the retina, allowing us to perceive the actual upright object that we are observing.

FUN FACT: The point at which the optic nerve connects to the retina, known as the **optic disc**, has no rods or cones, and light that strikes this region is not detected, leading to this region being known as the eye's "**blind spot**". However, since we have **stereoscopic vision**, or in other words, since the visual information reaching the brain comes from two "channels" (the left and right eyes), the brain "fills in" missing information from the blind spot of each eye with information obtained from the other eye!

Exercise 3.1: Find that Flower II (*Grades K-12*)

In the exercises on chemical olfaction, you learned that some insects (e.g., bees and flies) locate flowers by the particular odors they give off to advertise their available nectar supplies. Bees also use the visual sense to locate nectar sources, though they are not as restricted to vision as are the butterflies. Flower parts and their colors have evolved to attract particular insects. For instance, there are few green flowers, because flowers need to present a target to potential pollinators, and green flowers would be more difficult to locate amongst a plant's leaves. Different insect species are sensitive to different color patterns, and many insects (such as bees) can see into the ultraviolet spectrum, which has a much smaller wavelength than visible light, and is not visible to humans and most other vertebrates (birds are an exception). The images on the following page illustrate a comparison of how various flowers appear to vertebrates, and an approximation to how they might look to insects that can see into the ultraviolet region of the electromagnetic spectrum. As an interesting note, you may notice a similarity in the "Insect View" images to what you might see if the flowers were placed under a "black light". This is because a black light, which emits ultraviolet light (invisible to humans, though they also emit a small amount of visible violet light), can cause some objects to **fluoresce**, or emit light of a longer wavelength of light that is visible to humans. Therefore, the view of objects under a black light can reveal patterns that we would not otherwise be able to see, but that would be visible to bees and other insect pollinators. Many flowers that look otherwise uniform in color to us actually have striking patterns, often in a "bulls-eye" design to attract insect pollinators to the "target" area of the flower, where pollen can be transferred, and nectar rewards can be found. See the images on the following page for an example of how flowers might appear to insect pollinators, as compared to our view.



The following class demonstration will provide you with first-hand experience on the extent to which flowers are designed to attract insects.

Instructions:

- Find the "Vision" box, and take out the two flowers inside.
- Four volunteers from the class should be selected.
- Two of these volunteers should be designated as flower holders. Each flower holder should be given one of the included flowers, which they should hold by the stem, and wave gently (since flowers wave in the breeze!).
- The tube behind each flower should have some "nectar" in it (represented by a few red pompoms). If these are missing, add a few from the included packet of replacement "nectar".
- The other two student volunteers will serve as insects. Each will place a coffee stirrer straw in his or her mouth and should clasp their hands behind their backs.
- Assign one insect to a particular flower and the other to the remaining flower.
- Each "flower" and "insect" pair should face one another such that the flower tube is visible to the rest of the class.
- At the count of three, each insect should attempt to get its proboscis (straw) down into the nectar tube of its flower as it waves in the breeze. The object is to drag some nectar (a pompom) up the tube towards the flower head. There is no need to take the ball out of the tube; simply bring it up to the flower head.
- Repeat with several other insect volunteers.
- While engaging in the exercise of the insects dragging nectar toward the flower head, your teacher will make a table on the board indicating which flower was the

"winner" in each attempt. Does the data indicate one flower was more often associated with the winner? Why might that be? Discuss your reasoning with your teacher and other students.

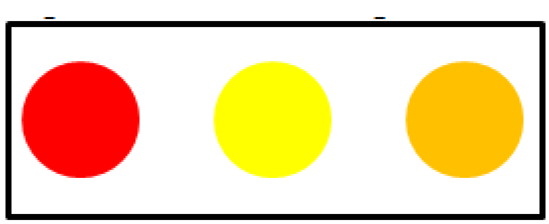
- After a bit of discussion, the class should examine the two flowers to see if they note any differences between them, and then consult the answer section of this workbook for additional information.

Exercise 3.2: Slap Snack Alarm (*Grades K-12*) & **Slap Snack Mimic** (*Gr. 3-12*)

Unless an animal is at the top of its food chain, it faces the problem of **predation**. That is, there are other animals that want to prey/feed on it. Because of their small size, insects are a major prey source to many other organisms, including mammals and birds. Insects have developed two prominent mechanisms of avoiding predation:

1. Many plant feeders incorporate noxious chemicals plants produce to avoid being eaten into their own tissues. This makes these insects taste bad, and many are even **poisonous** to eat.
2. Other insects have developed **venoms** which are toxins that can be injected into a predator by way of specialized hairs, stingers, or mouthparts. Anyone who has encountered the saddleback caterpillar or a yellow jacket wasp understands the repelling effect stings can have on a predator thinking about attacking a particular prey.

Both poisons and venoms are **chemical defenses** against predation. The value of the defense to a particular prey, however, is limited as it might be injured or swallowed by the attacking predator before the chemical defense is released. Thus insects and other animals that have chemical defenses also tend to be brightly colored. These prey are taking advantage of the fact that predators have the ability to learn, and with experience with a distasteful or stinging insect that is brightly colored, tend to avoid similarly colored organisms in the future. The common **aposematic**, or warning colors are red, yellow or a blend of the two, orange.

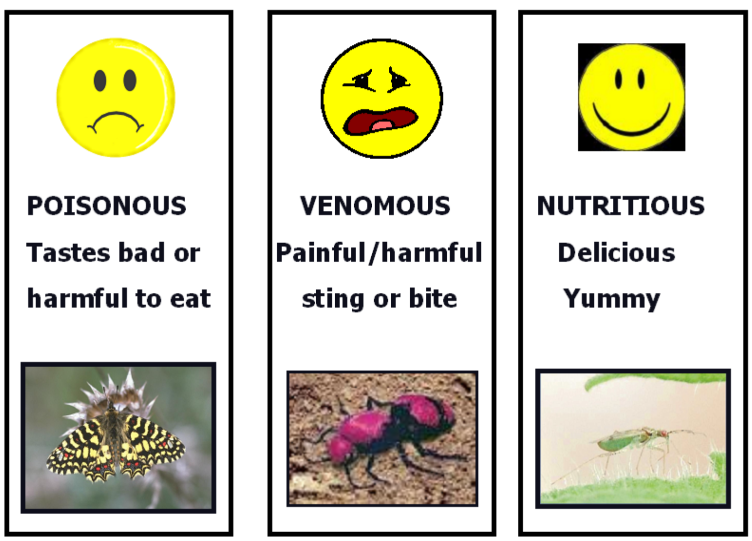


Common aposematic (warning) colors

Just as red, yellow, and orange warning signs attract our attention when we are driving down the road, red, yellow and orange colors on an animal attract the attention of predators. A young bird or mammal may initially be attracted to and eat one or two brightly colored insects, but quickly learns to avoid insects that have red, orange, or yellow patches, and associates these colors with things that are bad to eat.

In the following exercises, you will play the role of predators making decisions about what prey to eat. However, you will also be competing with your classmates, which simulates another real problem predators face: obtaining food resources that are limited.

Exercise 3.2a: Slap Snack Alarm (*Grades K-12*)



In this exercise, you will pretend that you are hungry birds looking for something to eat. You will play this game in small groups, which simulates the fact that many birds often search an area for food together. As you encounter a potential prey item, you need to very quickly decide whether to attack it or not. If you act too quickly and attack every prey item, you might end up eating a prey item that could make you sick, or that could injure you. However, if you are too slow in your response, an edible prey may escape, or another bird might get it first.

Instructions:

- Divide into groups of about 4 students.
- Each group will be given an "Alarm" deck of cards.
- One student should serve as the dealer, and the others as birds.
- The dealer will turn one card over and place it in the center of the group of birds. The first person to slap that card with his or her hand gets the prey item, and moves it to his/her pile.
- If no bird attacks a given card, the dealer moves it to a "not eaten" discard pile next to the original deck.
- Continue the foraging bout by offering all cards in the deck one at a time for potential predation.
- At the end, each individual should check the prey in his/her pile against the answer sheets shown in the answer section for this exercise at the end of this workbook.
- Each bird should remove one "nutritious" prey item card from their pile for every "poisonous" or "venomous" prey item card in their pile, representing the consequences of eating prey that could harm them.
- The number of cards each bird has left is their "food reward score" for the round. Which member of your group was the best forager (had the highest food reward score)?
- Also, the larger the number of "poisonous" and "venomous" prey item cards left in the "not eaten" pile at the end of the game, the better your group is at being "smart" predators.
- This card game can be extended so that those with the highest food reward score from each of the original groups can then compete in another round to determine an overall winner.
- Discuss the food reward score and the characteristics of the winning bird that allowed him or her to be a 'smart' predator.

<u>The Advantage of Good Vision to Predators</u> (*Grades 4-12*)

Sometimes you will hear about how a certain trait will give an animal a better *chance of survival*. What does that really mean? Let's pretend that you are a bird that can't see very well, so that you must choose a card (prey) without being able to see whether it is a good-colored insect or a bad-colored insect. If you randomly slap a card without seeing the color, are you more likely to get a good card or a bad card? The likelihood that something will occur is also called ***probability***. It is also known as *chance.*

For example, when you play a coin toss game you must guess if the coin will fall on its heads or tails side. There is a chance your guess will be right, and a chance it will be wrong. We can determine probability by using a ratio:

$$\boldsymbol{Probability = \frac{Number\ of\ Desired\ Outcomes}{Number\ of\ Possible\ Outcomes}}$$

In the case of the coin, there are two possible outcomes: heads and tails. There is one desired outcome: your guess (heads or tails). Therefore you can express the probability your guess is correct as:

$$\boldsymbol{Probability = \frac{Number\ of\ Desired\ Outcomes}{Number\ of\ Possible\ Outcomes} = \frac{1}{2} = 50\%}$$

One would say there is a 50% chance you will guess correctly.

- In the Alarm Deck, there are 13 "nutritious" cards, and 25 cards total. Use this information to answer the following questions:

Q1. If you can't see well and must choose your prey card at random, what is the probability that you will choose a good card?

Q2. Is the probability from Q1 better or worse than if you were to toss a coin?

Q3. Luckily, you can see very well. When you played the game, what percent of the cards that you chose did you get right? Was this better than your probability if you had to choose prey at random? How is having good vision a survival advantage for predators? Justify your answer.

$$\boldsymbol{Ratio\ of\ Your\ Success = \frac{Number\ of\ Good\ Cards\ You\ Picked}{Total\ Number\ of\ Cards\ You\ Picked} = \frac{?}{?} = ?}$$

Q4. Explain how competition with other predators when you played the game may have affected the ratio of your success.

- Be sure to put all of the cards back in the card case when you are finished, and to return these to the "Vision" box to be placed back in the wooden trunk.

Exercise 3.2b: Slap Snack Mimic (*Grades 3-12*)

Because many bad tasting and venomous insects escape predation due to their bright colors, many other species of insects "cheat" by producing similar bright color patterns. This is called **mimicry**, in which a species lacking chemical defenses mimics a **model** species (that *does* have chemical defenses) that occurs in the same habitat. The advantage to the mimic is that the predator may have previously experienced a capture attempt with the model species, and has learned to avoid insects with a similar appearance. In this exercise, you will be foraging birds feeding in groups individuals that are competing for food. You will be required to make a quick decision as to whether an insect is palatable (tasty) or not (chemical defenses present). The object is to receive the greatest food reward score. You will receive +2 points for taking a prey that is neither a model nor a mimic, and +5 points for taking a mimic. However you will suffer (-10 points) for taking a model (chemically defended) prey item.

Instructions:

- Divide into groups of 4 or 5 students sitting around a cleared desk.
- Each group will be provided with a deck of cards (labeled "Mimic 1" or "Mimic 2" on the backs of the cards.
- Examine the mimicry sheets in the answer section at the end of this book.
- Assign one individual as a dealer. The others will be birds in the foraging group.
- The dealer should construct a score sheet with the names of all birds on it, and a note to whether the "Mimic 1" or "Mimic 2" deck is used in the game.
- The dealer will turn one card over and place it in the center of the group of birds. The first person to slap that card with his or her hand gets the prey item, and moves it to his/her pile.
- If no bird attacks a given card, the dealer moves it to a "not eaten" discard pile next to the original deck.
- After each prey is captured, the bird can check the point value of the captured prey by placing the included red cellophane sheet over the card, which will reveal the point value. The dealer should then write this score down under that individual's name on the group's foraging score sheet. Possible scores for a particular prey are +2, +5 and -10, where +2 is the reward for taking a prey that is not a mimic or a model, +5 is the reward for taking a mimic, and -10 is the penalty for taking a harmful or distasteful model prey.

- The dealer should continue the foraging bout by offering all cards in the deck one at a time for potential predation.
- At the end, the dealer will add up all of the scores.
- The bird with the highest total score is the smartest and/swiftest predator in the group (has the highest fitness reward).
- Repeat this game a few more times, and then switch decks with another group. If you previously played the game with the "Mimic 1" deck, switch decks with another group that had the "Mimic 2" deck and vice versa. Repeat the game a few times with the other deck, as well.
- Have a class discussion concerning the differences in outcomes (the overall final scores) between the "Mimic 1" and "Mimic 2" decks. Can you explain why such differences might have been observed? Check the answers for this exercise at the end of the workbook for an explanation of why you might have observed such differences. Were your possible explanations correct?

<u>Why Are There Two Mimic Decks?</u>

Did you notice that finding nutritional prey items was easier or harder in one deck versus the other? The difference in these two decks is meant to tell us something important about mimicry: that mimicry works better in one situation than another. What exactly is the difference between these decks, and how does this apply to real world situations of hungry birds and their prey?

- Refer back to "The Advantage of Good Vision to Predators" in the previous "Slap Snack Mimic" exercise for tips on calculating probability.

Sometimes games like this one add complexity by making the outcomes worth more or less points (aka different ***payoffs***). Think again about a coin toss game. Imagine if you were going to toss a coin many times, but must first choose one of two different options:

Option 1: Heads will win you $2, if tails you lose $3
Option 2: Heads will win you $6, if tails you lose $4

Which game would *probably* result in the best payoff for you? You can figure this out by calculating the **expected value**. This is the *average* outcome that you would expect over time, if you played the game a lot. It is important to note that since chance is involved, this is only a predictor, and may not reflect your actual outcome. To get the expected value, you must first calculate all of the probabilities of each outcome (P_1, P_2, etc), then multiply each probability by its payoff (M_1, M_2, etc), then sum the terms:

$$\boldsymbol{Expected\,Value = M_1P_1 + M_2P_2 + \cdots + M_SP_S}$$

Let's try this for our two coin toss options to see which would give the better expected value:

Option 1: Heads will win you $2, if tails you lose $3

The probability of getting heads or tails, as we calculated earlier, is ½, therefore:

$$\boldsymbol{Expected\,Value = (2)\left(\frac{1}{2}\right) + (-3)\left(\frac{1}{2}\right) = -\frac{1}{2}}$$

In this case, you would expect to lose half a dollar each time. For example, after four tosses, you would expect to lose $2. Since the expected value is negative, this game probably won't be profitable to you over time. What about option 2?

Option 2: Heads will win you $6, if tails you lose $4

In this case, the payoffs have changed though the probabilities have not, so our new calculation is:

$$\boldsymbol{Expected\,Value = (6)\left(\frac{1}{2}\right) + (-4)\left(\frac{1}{2}\right) = 1}$$

With Option 2, each time you might expect to gain a dollar. Since the expected value is positive, this game probably will be profitable to you over time. Option 2 is better for you.

The cards in the mimic decks similarly add another level of complexity to the game because their values are different (worth either +2, +5 or -10).

First let's look at the cards in Mimic Deck 1:

Card Type	**Card Value**	**Number of Cards**
Nutritious (non-mimic)	+ 2	15
Mimic (nutritious)	+ 5	4
Model (poisonous/venomous)	- 10	6

Q1. If you selected a card at random from Mimic Deck 1, what is the probability that the card is a mimic card?

Q2. If you selected a card at random from Mimic Deck 1, what is the probability that the card is a model (poisonous or venomous) card?

Q3. If you selected a card at random from Mimic Deck 1, what is the probability that the card is a nutritious non-mimic card?

Q4. Using the card values and the probabilities you calculated in Q1-Q3, what is the *expected value* for one card drawn from Mimic Deck 1?

Now let's look at the cards in Mimic Deck 2:

Card Type	Card Value	Number of Cards
Nutritious (non-mimic)	+ 2	15
Mimic (nutritious)	+ 5	7
Model (poisonous/venomous)	- 10	3

Q5. If you selected a card at random from Mimic Deck 2, what is the probability that the card is a mimic card?

Q6. If you selected a card at random from Mimic Deck 2, what is the probability that the card is a model (poisonous or venomous) card?

Q7. If you selected a card at random from Mimic Deck 2, what is the probability that the card is a nutritious non-mimic card?

Q8. Using the card values and the probabilities you calculated in Q5-Q7, what is the *expected value* for one card drawn from Mimic Deck 2?

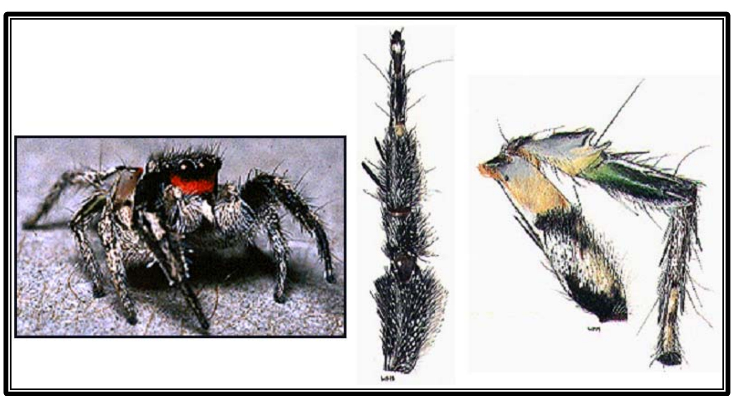
Q9. Compare your answers from Mimic Decks 1 and 2. In what ways are Decks 1 and 2 quantitatively different? Which deck is "easier" on predators? Therefore, under what conditions does mimicry work best for prey? Does this make sense? Justify your answer.

Exercise 3.3: Jumping Spider Dances

The two senses used in complex communication are vision and hearing. Vision is particularly important in male courtship of females. Species-specific color patterns and the complex movements used to display them help prevent wasted mating attempts between species. Thus biologists often use courtship sequences to identify species relationships. Females also choose among courting males of the same species on the basis of the quality of displays they offer. Birds, lizards, and fish are perhaps best known for these colorful courtship sequences.

From left to right: Male peacocks are a common example of elaborate male courtship displays in birds. The males of many anole lizards have a brightly colored dewlap (throat flap) that they extend in territorial and courtship displays. Male betta, or Siamese fighting fish, displaying colorful, showy fins.

One would not expect spiders to have elaborate visual courtship sequences, as they generally have very poor vision, and thus are not very colorful. Major exceptions can be found in members of the Salticidae, or jumping spider family. Males have bright color bands and patches on the body and legs that are displayed in elaborate dances. Dr. Wayne Maddison and his students have been examining species relationships within the genus *Habronattus*, in part through examination of male dances.



From left to right: Male *Habronattus coecatus*, showing red face band; illustration of leg-raising behavior in a *H. coecatus* courtship; banding on the third leg of a male *H. coecatus*. (Images courtesy W. Maddison).

The following exercises use video clips of the courtship dances of several species of jumping spiders, illustrating differences in behavior among species. Younger students will use these videos to learn and perform a spider dance, and older students will learn to develop an **ethogram**, and then compare ethograms among species.

Exercise 3.3a: Learn a Spider Dance (*Grades K-1*)

Instructions for Teachers:

- Locate the Unit 10 CD, and insert it into your computer's disc drive.
- Find the folder named "Jumping Spider Dances," and open it. This folder contains videos of the courtship dances of eight species of *Habronattus*. Below is a list of these species, as well as the meaning of the species name of each:
  - *Habronattus americanus* ("American")
  - *H. tarsalis* ("sole of the foot")
  - *H. tuberculatus* ("knobby")
  - *H. coecatus* ("lacking color")
  - *H. jucundus* ("merry")
  - *H. decorus* ("elegant")
  - *H. altanus* (" high altitude")
  - *H. carolinensis* ("Carolina")
- Allow students to view each of the species' courtship dances several times, and choose (by vote) one whose dance they will learn. Note that some of the dances are quite long, and thus are split into 3 clips in order from start to finish.
- Play the clip again, now concentrating on the first action seen. Pause the video and have a class discussion to describe this particular action, and allow students a chance to practice this first "dance move". Since we only have 4 limbs as opposed to the spider's eight, encourage students to pay attention to (and be creative with) the position of their arms and legs to reflect motions of different legs of the spider.
- Repeat the previous step until each spider action has been described and duplicated by the students. Have the students keep track of the order of actions performed, which motions were repeated, etc.
- Once the sequence of actions for the spider's dance has been determined and duplicated, put all the moves together, and perform the dance together as a class. You may even wish to give a performance of your spider dance to another class or the school!

Exercise 3.3b: Develop an Ethogram (*Grades 2-12*)

What is an ethogram? An ethogram is a ***quantitative description of the natural behavior of an animal species***. In the case of this exercise, however, you will limit your ethograms to the behavior (the courtship dances) of males directed towards females of various *Habronattus* species.

The goal of this exercise is to develop an ethogram, or step by step account of the courtship dance of one species of the jumping spider genus *Habronattus*.

Instructions for Teachers:

- Locate the Unit 10 CD, and insert it into your computer's disc drive.
- Find the folder named "Jumping Spider Dances," and open it. This folder contains videos of the courtship dances of eight species of *Habronattus*. Below is a list of these species, as well as the meaning of the species name of each:
    - *Habronattus americanus* ("American")
    - *H. tarsalis* ("sole of the foot")
    - *H. tuberculatus* ("knobby")
    - *H. coecatus* ("lacking color")
    - *H. jucundus* ("merry")
    - *H. decorus* ("elegant")
    - *H. altanus* (" high altitude")
    - *H. carolinensis* ("Carolina")
- Allow students to view each of the species' courtship dances several times, and choose (by vote) one for which they will develop an ethogram. Note that some of the dances are quite long, and thus are split into 3 clips in order from start to finish.
- Play the clip of the chosen species again, instructing students to count the number of individual actions that occur in the dance, and to note this number. After counting the number of actions that occur in the dance, have a class discussion to sort out any differences in the numbers of actions observed.
- After an agreement on the number of actions has been reached, students should then make a list of numbers on a sheet of paper corresponding to the total number of acts they counted in the dance, with the teacher making a master list on the board.
- Play the clip again, now concentrating on the first action seen. Each student should write a description of this action pattern beside #1 on their list of numbers.

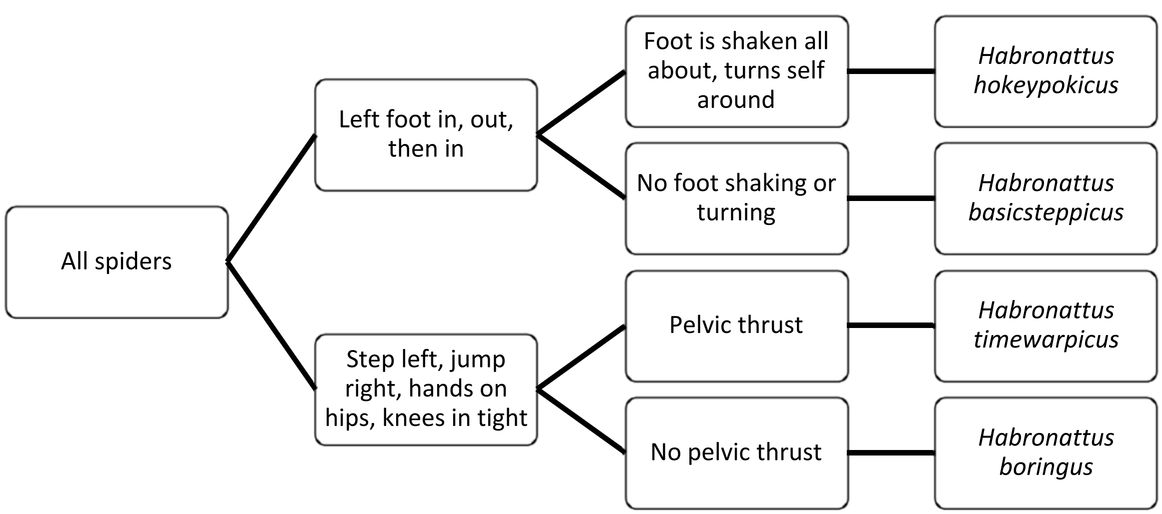
- The class should have a discussion of this action, and come up with a name that best describes it. Use this name whenever you see this action again during the course of the dance. This will eliminate the need to write down the description each time.
- Repeat these steps until all of the different actions have been defined and assigned a name.
- Now view the dance again, observing the sequence of events from beginning to end, writing down the actions in the order that they occur. You may need to repeat the clip a number of times to get all number slots filled.
- Now count the frequency of each of the different actions. How many times does each different action occur in the entire clip? Make a table using tally marks for each time an action occurs.
- A **table** provides you with an organized record of the collected data. You can then use the data to make different types of graphs or use it as an easy-to-read reference for further study.
- When you have completed tallying the actions, find the total of your tally marks for each action. Construct a bar graph that compares the number of times each individual action occurs in the dance, with a bar for Action #1 and its name, Action #2 and its name, etc. Which actions are most frequent? Which actions are the least frequent? Remember to include the important components of your bar graph: an appropriate scale for your data, the labels for the axes, and a descriptive title.
- Use your collected data to construct another graph to detect patterns that may occur in the dance. Your x-axis, or *horizontal* axis, will represent elapsed time. The y-axis, or *vertical* axis, will represent the different actions observed in the dance. As the video clip is played, you will move from left to right on the x-axis, indicating changes in action with points corresponding to the action number/ name on the y-axis. Do you see any patterns in the action sequence? Are some of the actions more frequent than others? Are some actions present in the beginning but not toward the end, or vice-versa?
- Once your list is complete, you can perform the dance and describe the behavior in terms of an ethogram. Are there repeated patterns, just as in the repetition of the chorus of a song? Are some behavior patterns more frequent at the beginning of the sequence, and replaced by others later?

Exercise 3.3c: Comparing Ethograms (*Grades 8-12*)

The goal of this exercise is to compare the dances exhibited by different species of jumping spiders in the genus *Habronattus*, and hypothesize relationships between species based on the actions they perform.

Instructions:

- Divide into groups of 3-4 students each.
- Each group will be assigned a different *Habronattus* species.
- Following the same procedure as in the previous exercise, your group should complete an ethogram for your group's species, which you will share with other groups.
- When you have completed recording the actions and making your graphs, use the notes that tell you the actions and the order in which they occur, and see if your group can teach your species' dance to the rest of the class. You may even wish to have a "spider dance-off" in your classroom!
- After ethograms have been developed for each of the presented *Habronattus* species, you should use the set of ethograms to cluster together species that have the most elements (action patterns) in common.
- Develop a branching diagram of your choosing that reflects the relationships among the different species. Below is an example of a branching diagram used to describe the differences and similarities in the dances of four very hypothetical species of *Habronattus*.



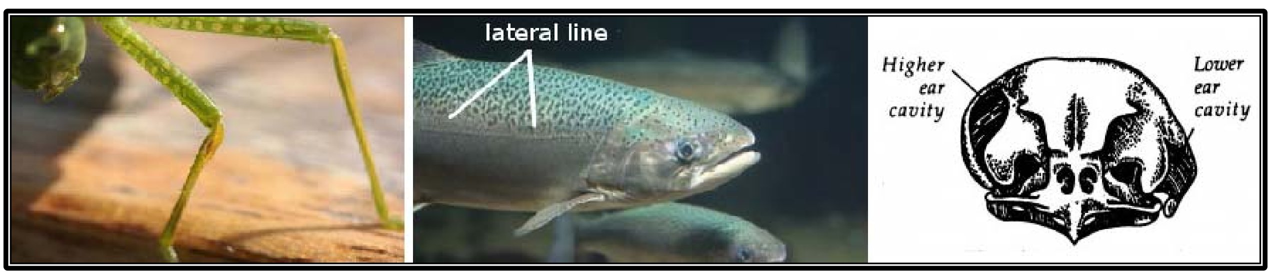
- Compare the species relationship tree you have developed to that developed for these same species using molecular sequence data (found in the answer section for this exercise at the end of this book), and answer the following questions:
- Do species that are most closely related in their genetic make-up share more behavior patterns in common than more distantly related species?
- Are there qualitative differences among the species (different behavior patterns), or are the differences merely quantitative (same behavior patterns but differences in relative frequencies of various actions among species)?

NOTE: You can calculate the relative frequency (in percent) of an action by dividing the total number of occurences of that action by the total number of actions altogether, and multiplying this result by 100:

$$\boldsymbol{Relative\ frequency\ of\ action\ A}(\%) = \left(\frac{\boldsymbol{Number\ of\ occurrences\ of\ action\ A}}{\boldsymbol{Total\ number\ of\ all\ actions}}\right) \times \mathbf{100}$$

Exercise 4: Hearing is a Vibrational Sense

Many organisms have sensory cells that detect the movement of air or fluids. Various "singing" insects have external "ears" in the form of a **tympanum**, or membrane that is sensitive to vibration. Crickets and katydids, for example, have a tympanum on the tibia of each of their front legs, and grasshoppers possess a tympanum on each side on the first segment of their abdomens. Terrestrial (land dwelling) vertebrates have sensory cells concentrated in two ears, one on either side of the head, that they use to hear sound. Even fish and snakes (and a few lizards and other reptiles), which have no external ear or ear opening, have inner ears). Additionally, fish also detect vibration in water through the use of their **lateral line system**, a series of receptor cells running along their sides, which can sometimes be seen as a faint line or groove running from the gill to the base of the tail. In the vertebrate ear, sound waves hitting the ear cause movement of the fluid in a chamber housing sensory hair cells. The movement of the fluid causes the fine hairs to bend, and receptors in each hair cell send this information to the brain for processing. The sense of hearing is very important and well-developed in nocturnal animals, since it is difficult to see at night, and such animals communicate mainly by sound.



Left: A katydid, with the tympanum visible on the front tibia (image credit: Whitney Cranshaw, Colorado State University). **Center:** The lateral line on a rainbow trout (image credit: Tomas Hellberg). **Right:** The unusual asymmetrical arrangement of ear openings in owls helps them pinpoint sounds accurately in the dark.

Exercise 4.1 and **Exercise 4.2** demonstrate how bats and spiders, respectively, use the vibrational sense to find food. **Exercises 4.3** and **Exercise 4.4** examine the calls that male frogs use to find mates, as well as provide further information on the science of sound waves, and how scientists can visualize sound.

Exercise 4.1: Bat Echolocation (*Grades K-12*)

Bats use high sound pitches that are at the upper limit of human hearing. They actually produce ultrasonic calls that they send out into the night air in search of flying insects. When these sound waves hit a flying object, the signal bounces back, just as a ball you have thrown at a wall comes back towards you. Receptors in the bat's ears are tuned to screen the ultrasonic playbacks to detect potential prey, and repeated calling permits the foraging bat to locate these prey.

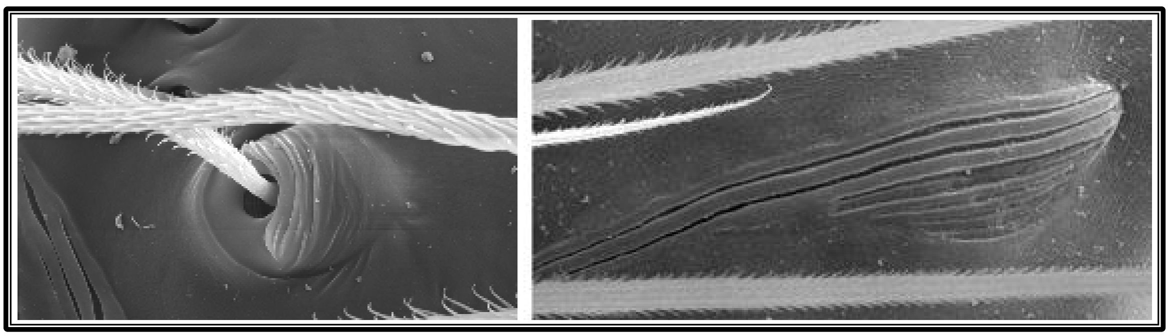
- Choose an individual who will be the bat in this exercise. This person should put on the included blindfold.
- Five additional students should be selected as moths, the favored prey of most bats.
- In a place free of furniture and other objects that our bat might trip on, the rest of the class should form a circle around the bat and moths.

The goal of this exercise is for the "bat" to locate all of the "moths" by echolocation.

- The bat does this by calling out "BAT".
- The moths must reply each time they hear the word bat by calling out "MOTH".
- The bat should attempt, after hearing each reply, to move towards the call of the nearest moth.
- The moth is captured if the bat touches it with his/her hand, at which point, the moth should exit the circle, and no longer respond to the bat's calls.
- You might time this exercise to see if some students are better than others in using echolocation.
- Be sure to place the blindfold back in the appropriate box at the end of this exercise.

Exercise 4.2 The Vibration Sense of Spiders (*Grades K-12*)

Most spiders (with the exception of the jumping spiders mentioned in Exercise 3) can see no more than a couple of centimeters distant (2.54 cm = 1 inch). Therefore, the sense of "hearing" is the primary sense in most spiders. When referring to spiders, however, the term "vibrational sense" is used rather than "hearing," which is a term whose use is typically restricted to use when referring to animals with actual ears. Spiders' do have "ears" in a sense, in that they do have organs that detect vibrations, similar to true ears. However, a spider's vibration sensing organs are found primarily on their legs, but also in various other locations on the body. These organs include **lyriform organs**, which are grooves, attached to nerve endings, in the spider's exoskeleton. **Trichobothria** (singular = trichobothrium) are other vibratory sense organs in spiders. Trichobothria are specialized hairs (distinct from the many other hairs on a spider's body) that fit into a cup-like socket. These specialized hairs are also sensitive to vibrational cues. As a spider sits on its web, an insect hitting the web causes the silk strands of the web to move, which in turn causes the spider's feet and legs to move. These vibrations also bend and vibrate the trichobothria, as well as change the shape of the exoskeleton around the openings of the lyriform organs, and the nerves associated with both the trichobothria and lyriform organs then send the vibratory information on for processing. As in bats, a spider's vibratory sense organs are tuned to particular vibration patterns. Information on the type and size of insect hitting the web is obtained through this sense. In this exercise, you will explore the importance of this vibrational sense to spiders by getting the chance to play the role of a spider or of a spider's insect prey.



Left: Scanning electron micrograph of trichobothria on a spider's leg. Note the cup-like socket of one trichobothrium (image credit: Jeremy Miller). **Right:** Scanning electron micrograph of the lyriform organ in *Amaurobius fenestralis* (image credit: University of Bonn).

- Divide into groups of 6 individuals.
- One person in each group will be the spider and the other five students will play the role of insects.
- Locate the "Vibration Sense of Spiders" box in this unit, which contains a wooden block with fishing lines attached, as well as a blindfold.
- First unwind the fishing lines wrapped around the wooden block in the box.
- The designated spider should hold the wood block in one hand.
- Each insect should then take one of the monofilament lines and move away from the spider.

- The spider will then position his/her other hand on the top of the wood block such that one finger is resting on each of the five lines.
- The spider should then be blindfolded, to reflect the poor visual capabilities of most spiders.
- All moths should make sure that they are backed away from the spider until each of their lines is taut.
- The teacher or a selected student should tap one of the moths, who will pluck his/her thread.
- When the spider detects the pluck, it should pull on this line. Did the spider find the correct prey?
- Switch roles, with different groups and individuals getting chances to serve as spider and moths.

Exercise 4.3: What Kind of Frog? (*Grades 3-12*)

Animals use the vibrational sense to detect prey and to avoid predators. Also, just as when people talk and others listen, animals also communicate through the production of sounds and the processing of these sounds. Like birds, male frogs and toads sing to attract females to them. It is important to both sexes that they locate (and attempt to mate with) only individuals of the same species, so each species has a unique song or call. However, the calls of closely related species are more similar to one another than are other frog or toad calls. In Tennessee, we have three major groups of frogs: the true frogs, the toads, and the tree frogs (see figures on page 66). In this exercise, you will learn the differences in calls among the three major frog groups, and will then be asked to assign the calls that you hear to the correct group.

- Take out a sheet paper and make a list of numbers from 1-11.
- Your teacher should locate the Unit 10 CD, and place it in the disc drive of your classroom computer. After opening the folder marked "Frog Calls," the teacher will play track 1 to introduce this exercise. Listen closely to the guide as he describes the general characteristics of the calls of three major groups of frogs.
- On track 2, you will hear several calls, numbered 1-11. As you listen to each call, try to decide whether it was made by a true frog, tree frog, or a toad, and write these answers beside the appropriate number on your answer sheet.
- On track 3, the guide will play the calls again, telling you what animal produced it.
- You may also check your answers in the section for this exercise at the end of this workbook.

TRUE FROGS

Green Frog (*Rana clamitans*)

American Bullfrog (*Rana catesbiana*)

Pickerel Frog (*Rana palustris*)

Pig Frog (*Rana grylio*)

Southern Leopard Frog (*Rana sphenocephala*)

TOADS

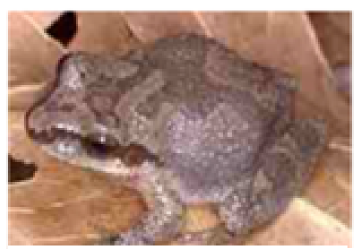
American Toad (*Bufo americanus*)

Fowler's Toad (*Bufo fowleri*)

Southern Toad (*Bufo terrestris*)

TREE FROGS

Brimley's Chorus Frog (*Pseudacris brimleyi*)



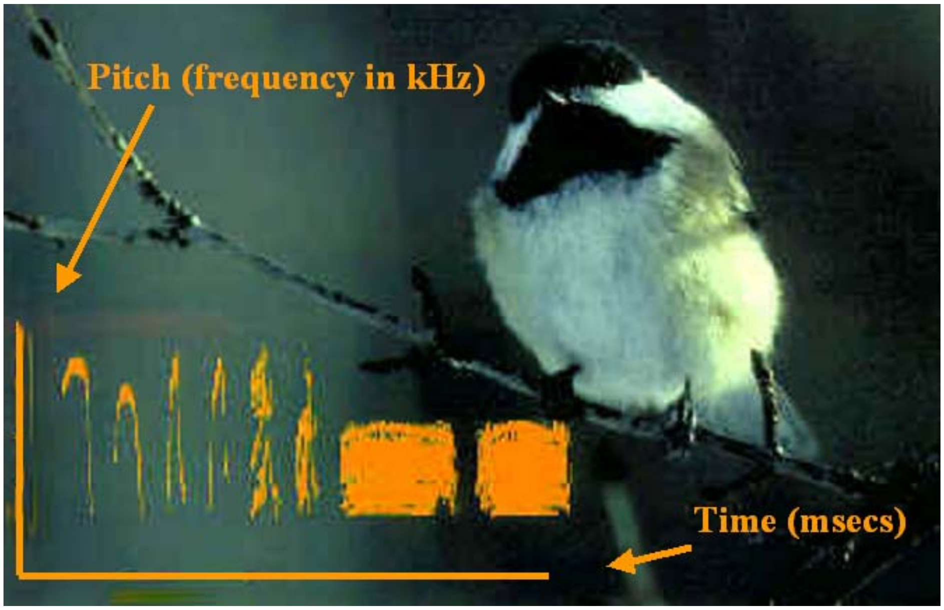
Mountain Chorus Frog (*Pseudacris brachyphona*)

Southern Chorus Frog (*Pseudacris nigrita*)

Upland Chorus Frog (*Pseudacris feriarum*)

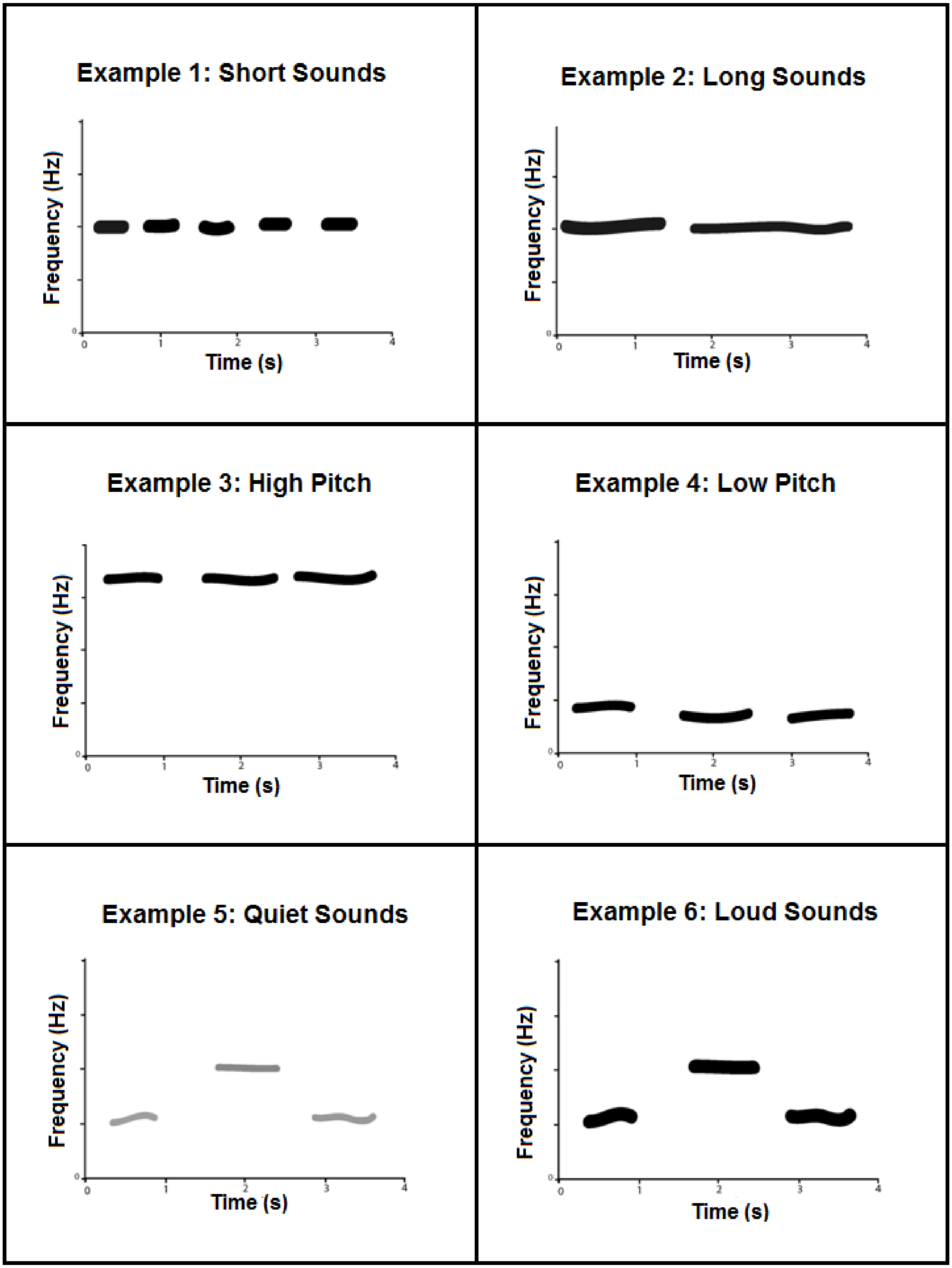
Exercise 4.4: Frog Calls on Paper: Reading Spectrograms (*Grades 6-12*)

It is easy enough to listen to songs made by various frog and toad species and detect differences among them. Biologists, however, need to be able to measure the differences (**quantify** them) and determine the extent to which these calls vary. We cannot simply take out a ruler and measure the differences in calls as we might do with the length of a leg or the height on an individual. Nor can we take out a color chart and assign a color shade to it as we might do for eye or skin color. One of the most basic techniques biologists use to analyze non-visual traits is to present the information graphically, a form that can be measured visually. Sounds can be converted to sound **spectrograms**, in which they are laid out in two dimensions (time and frequency or pitch) as shown on the following graph of the chickadee's song.

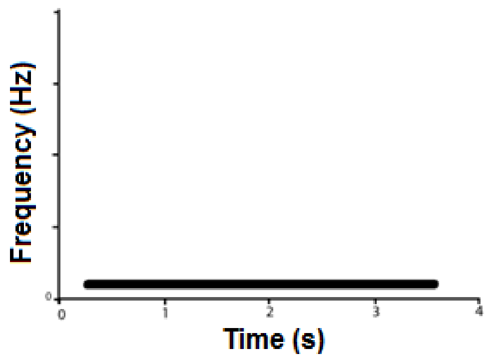


In this exercise, you will learn how to read spectrograms. Your challenge in the end will be to identify the spectrograms that belong to each of the mystery calls made by various true frog, tree frog, and toad species.

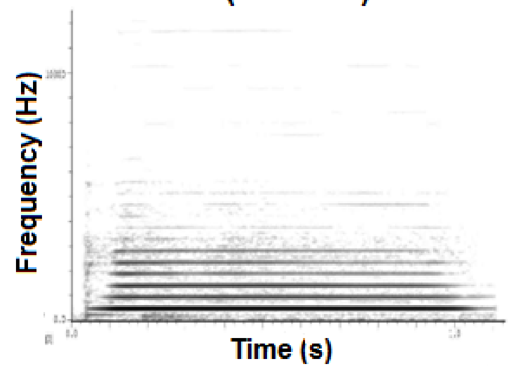
- Find the CD for Unit 10 with the frog picture on it, and open track 4 for an introduction to this exercise**.**
- Next, listen to track 5. As you listen to this track, observe the spectrograms of the various sounds on the track. See if you can begin to form a mental connection between the graphical depictions of the sounds, and the sounds themselves.


Example 1: Short Sounds
Frequency (Hz)
Time (s)
Example 2: Long Sounds
Frequency (Hz)
Time (s)
Example 3: High Pitch
Frequency (Hz)
Time (s)
Example 4: Low Pitch
Frequency (Hz)
Time (s)
Example 5: Quiet Sounds
Frequency (Hz)
Time (s)
Example 6: Loud Sounds
Frequency (Hz)
Time (s)

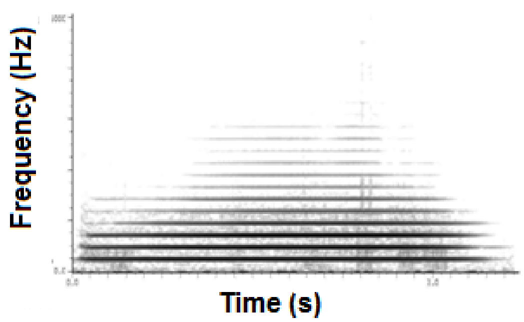
Example 7: Simple Sound (Sine Wave)



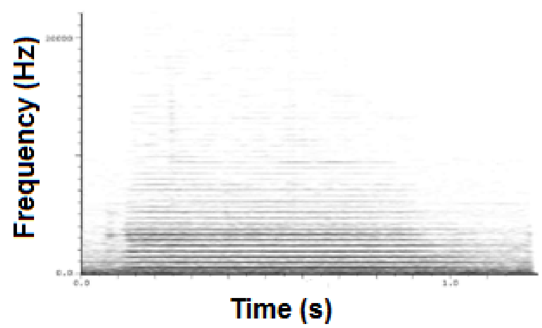
Example 8: Complex Sound (Clarinet)



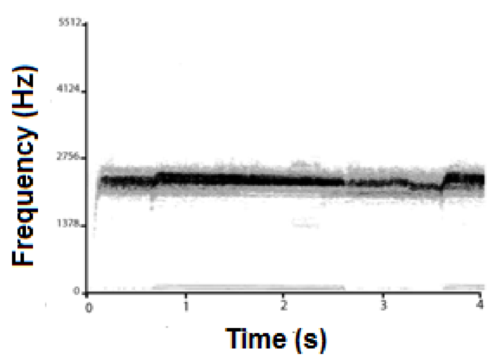
Example 9: Complex Sound (French Horn)



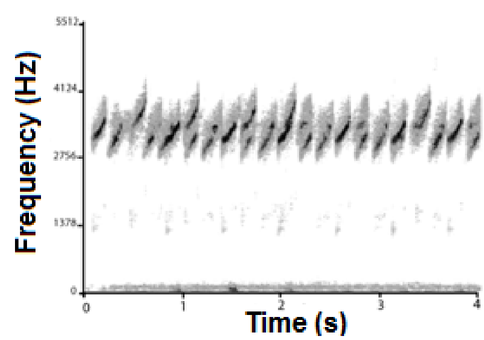
Example 10: Complex Sound (Violin)



Example 11: Animal Sound (Toad)



Example 12: Animal Sound (Tree Frog)



- After you have listened to each of the various sounds, and examined their spectrograms on the previous pages, look back at the spectrograms, and fill in the following chart, verbally describing the differences in the spectrograms of the pairs of sounds in the chart.

Spectrogram Comparison Chart

Comparison	Difference in the Spectrograms
Short vs. Long Sounds (Examples 1&2)	
High vs. Low Pitch (Examples 3&4)	
Quiet vs. Loud Sounds (Examples 5&6)	
Simple vs. Complex Sounds (Sine wave vs. Clarinet) (Examples 7&8)	
French Horn vs. Violin (Examples 9&10)	
Toad vs. Tree Frog (Examples 11 & 12)	

- After going over the previous information about spectrograms, discuss the following questions as a class, and share your ideas.

- What were the similarities in your answers with those of your classmates? What were the differences?
- What would you expect a spectrogram to look like that was of a pencil being tapped on a desk?
- What would you expect a spectrogram to look like of a person yelling "Heeeelloooooo"?

Matching Frog Calls to Spectrograms

Now you will be challenged to place several frog species with the appropriate graphical representations of their calls.

- Listen to instructions for this exercise on track 6.
- Go to track 7 to listen to the calls of the frogs pictured below.
- Try to match each call to the correct spectrogram on the following page.
- Explain why you chose to match that spectrogram to each frog call. You may use your chart and the example spectrograms to help you.

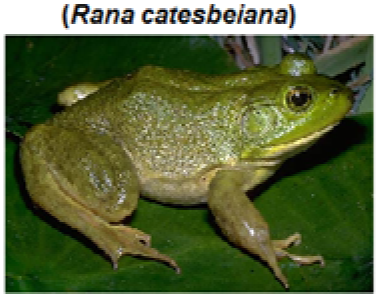
Pictures and identities of frogs for matching exercise

Call 1: Mountain Chorus Frog (*Pseudacris brachyphona*)

Call 2: Southern Chorus Frog (*Pseudacris nigrita*)

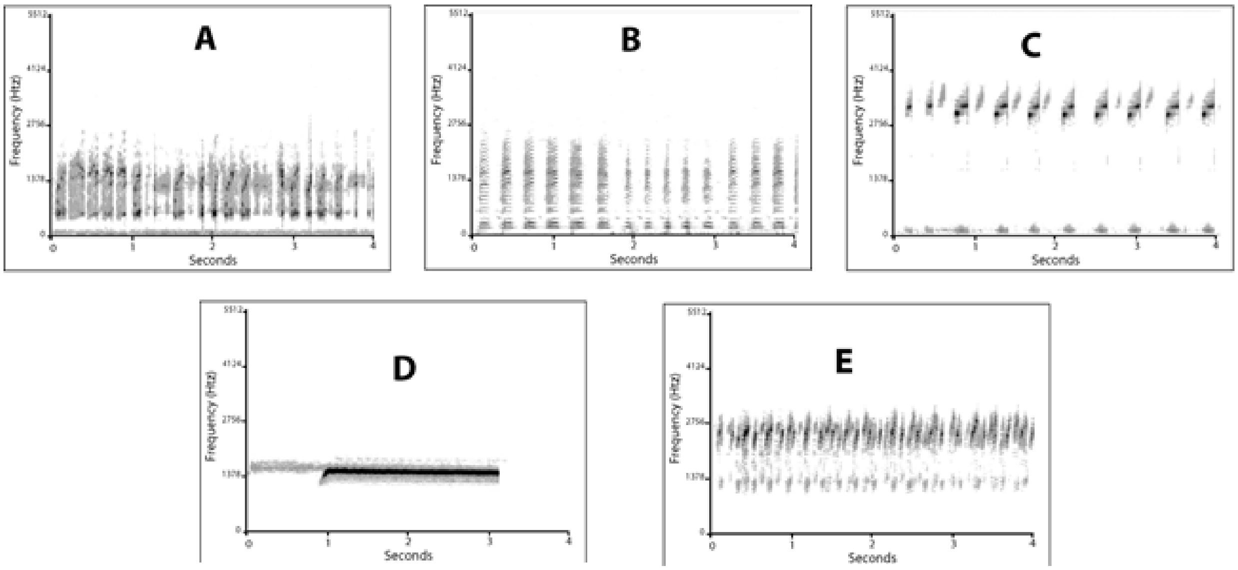
Call 3: American Toad (*Bufo americanus*)

Call 4: American Bullfrog (*Rana catesbeiana*)



Call 5: Southern Leopard Frog (*Rana sphenocephala*)

Spectrograms to be matched to frog calls



- Check your answers in the section for this exercise at the end of this workbook. How did you do? Were there any of the frog calls that were very easy to assign to a spectrogram? Were there others that were very similar, and more difficult to assign to spectrograms?

Open-Ended Extension: Collect images of spectrograms from the web, and describe characteristics of the sounds that they represent (frequency, length, etc.), and see if you can imagine what the sound represented in the spectrogram is like. If you find any that have sound clips that play the sound represented in the spectrogram, listen to them and see if you were correct in your thoughts of what the sound would be like!

The Basics of Hearing in Mammals

At this point, you might be wondering exactly how hearing works in humans. Hearing, as mentioned earlier, is very similar in most vertebrates, and involves the ears. In mammals, including humans, the structure and function of the ear is even more similar. Below is a diagram showing the parts of the human ear. Take a moment to familiarize yourself with these parts, and then read on for a basic description of how hearing works in humans.

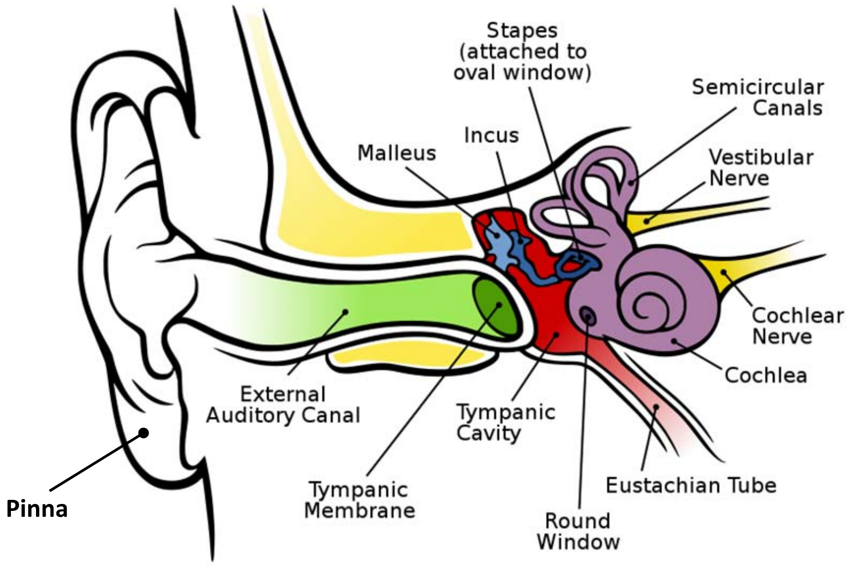


Diagram of the human ear. *Image credit: Chittka L. Brockmann*

1. The **pinna**, or **outer ear**, acts like a funnel to collect sound waves from our environment.
2. These sound waves then travel down the **external auditory canal**, and eventually strike the **tympanic membrane** (eardrum).
3. The sound waves striking the eardrum cause it to vibrate, as well.
4. These vibrations travel from the tympanic membrane to three tiny **ossicles**, or **small bones**, in the tympanic cavity in the **middle ear**. These ossicles, in the order of which vibrations reach them, are the **malleus** (hammer), **incus** (anvil), and **stapes** (stirrup).
5. The stapes sits against the **cochlea**, a coiled, fluid filled structure of the **inner ear**. The point at which the stapes contacts the cochlea is a small, membrane covered opening known as the **oval window**. When the stapes vibrates against the oval window, this causes fluid inside the cochlea to vibrate, and move along the coil of the cochlea, where it eventually reaches an area called the **organ of Corti**, a region containing (in humans) between 15,000-20,000 auditory receptors, each of which has its own **hair cell**. The vibration of the fluid within the cochlea and organ of Corti also causes these hair cells to vibrate.
6. The vibration of the hair cells in the inner ear stimulates them, causing them to pass this information to the **cochlear nerve**, which carries the signal to the brain for processing, at which point it is interpreted as sound. Since each of the hair cells within the organ of Corti vary in thickness and stiffness, they vibrate at different rates, depending on the nature of the incoming sound waves. Because of this, different sounds (in terms of frequency, intensity, etc.) result in

differences in the intensity and rate of vibration of these hair cells. This ultimately results in different combinations of signals from each of the hair cells, which can be processed by the brain and interpreted as differences in sound.

In case you were wondering about the other parts in the diagram, the **round window**, another membrane-covered opening in the cochlea acts as sort of a "release valve," which can bulge out to accommodate increases in fluid pressure within the cochlea. The **semicircular canals** and **vestibular nerve** in the inner ear function primarily in our sense of balance. The vestibular nerve actually joins the cochlear nerve, however, to form a single major **cranial nerve**, the **vestibulocochlear nerve**, that simultaneously supplies our brain with information on sound and balance for processing.

Part II: Environment and Learning

Behavior, like morphological traits such as size and coloration and physiological traits such as heart rate and the mechanics underlying sensory perception, is **inherited** (passed on from parents to offspring through genes). Behavior differs from the other traits though in the extent to which it can be modified by environmental influences. Behavior shows a much higher level of **plasticity**, or flexibility, and this reflects learning and mental processing. Thus, experience influences subsequent behavior. The exercises in this section explore environmental effects on behavior, and the mental capabilities of animals in solving environmental challenges. Remember that when we refer to the environment of an animal, we mean both **abiotic** (physical) features such as temperature and wind, but also **biotic** features such as prey, predators, and even other members of the same species.

In **Exercise 5: Temperature Effects on Call Rates**, students will explore a physical environmental factor on calling behavior in both frogs and crickets.

In **Exercise 6: T-Maze Experiments**, students can use provided T-mazes in an open-ended fashion to explore questions regarding preferences and learning abilities in small invertebrates.

In **Exercise 7: Caching Food for Times of Famine**, students will simulate a population of squirrels employing various behavioral strategies for caching food, as well as a biotic selective force: "cheaters" that want to steal their acorns.

Exercise 5: Temperature Influences Call Rates (*Grades 3-12*)

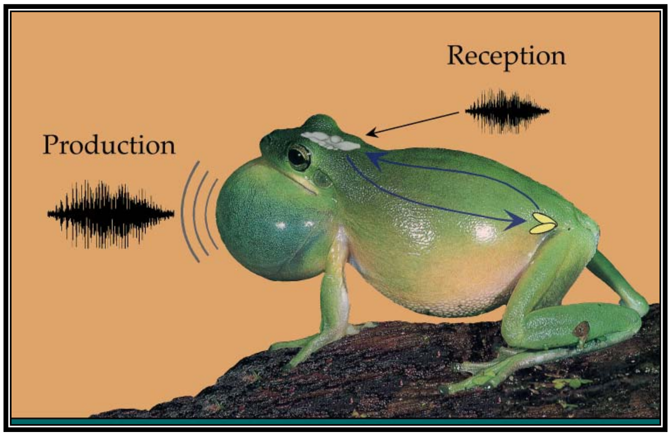
Ectotherms (***ecto*** = "outside", ***therm*** = "temperature") such as toads and crickets do not have an internal mechanism of controlling their body temperatures. Thus the body temperature of a frog in the water is the same as that of the water and the body temperature of a cricket and a frog sitting near a pond are the same as air temperature. Male frogs and crickets use muscle actions to produce their calls. Because muscles work faster and more smoothly at warmer temperatures, one might expect that on cold nights, some aspect of the call such as its rate of repetition might be decreased compared to patterns exhibited on warm nights. Where environments have this influence, females processing the male calls would either have to correct for air temperature ("do the math") or their processing of the calls would have to be temperature-dependent as well. In this exercise you will calculate the effect temperature has on frog and cricket songs. First, however, we will discuss a little about graphs, and how they are useful to scientists. You will then use graphs to help you understand how changes in temperature affect the characteristics of the songs of frogs and crickets.

Scientists use many different types of **graphs** to organize data because graphs provide a *visual display of information* so that changes or trends can be easily determined. The kind of graph we choose for our data depends on the type of experiment we conduct, and what we want the collected data to explain.

If you want to compare different items within a group, you might use a **bar graph**. You can use a **circle graph** (sometimes called a **pie chart**, because the sections look like slices of pie!) to show the size of different elements within a group (which one is the most, the least, etc.). You can use a **line graph** to show how something changes over time, or you can use a **scatter plot** to give you a kind of diagram of the data that allows you to see trends in the data. For example, do frogs call more in warmer weather or cooler weather? A scatter plot can give you a visual representation of that information by using temperature for one axis and number of call notes for the other axis.

Exercise 5.1: Temperature and Frog Call Rates (*Grades 3-12*)

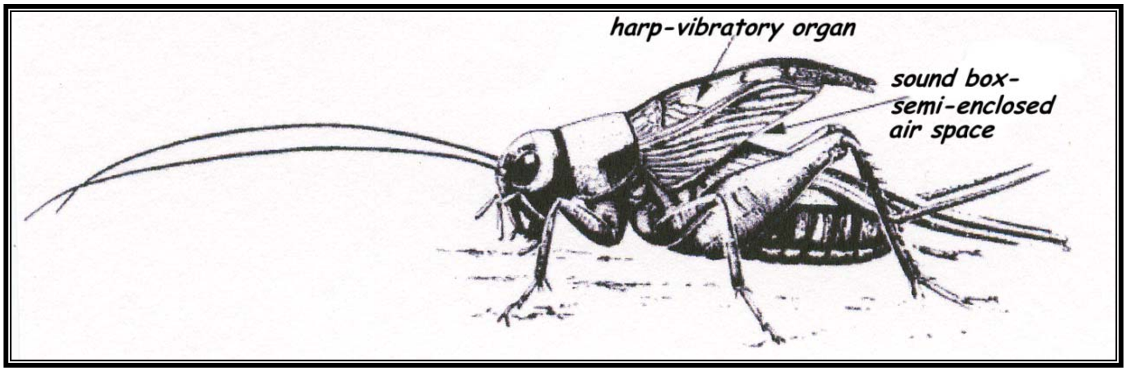
Frogs produce sounds by forcing air through the **larynx** (the upper end of a windpipe that contains vocal chords). The air vibrates the vocal chords and a special **vocal sac** is blown up like a balloon to amplify the sound (make it louder). What instrument does this remind you of? A Scottish bagpipe, perhaps?



- Find out how temperature affects call songs by finding **Exercise 5.1** on the **Unit 10: Behavior** CD.
- You will need a piece of paper, a pencil and a ruler to complete this exercise.
- First, listen to the introduction on track 8.
- After the introduction, you will be given instructions to the exercise on track 9.
- Complete the exercise presented on tracks 10-22.

Exercise 5.2: Temperature and Cricket Call Rates (*Grades 3-12*)

The male cricket song consists of a series of chirps. The chirp is produced by a process similar to that of a person playing a violin. The wing moves over a comb-like structure (bow over strings) that is positioned on a sound-box filled with air. The sound box amplifies the sound (makes it much louder).
You will need a piece of paper, a pencil and a ruler to complete this exercise.



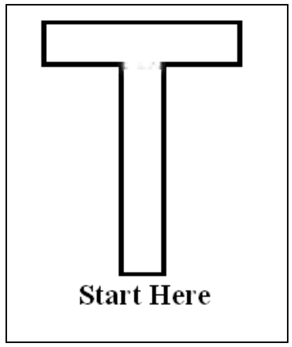
- Find the **Unit 10: Behavior CD**.
- Go to track 23 for introduction to temperature effects on calls.
- Go to track 24 to listen to a cricket call.
- Play tracks 25 - 38 for the activities associated with **Exercise 5.2**. At the end, you will be able to tell air temperature from the number of chirps a cricket makes in its call in a 10 second interval.

Exercise 6: Animal Choice: The T-maze (*Grades 3-12*)

When you hear the word "maze", you may think of mazes in a puzzle book, or perhaps a maze made of hedges or corn, where you start at one end and try to find the exit at the other (see figures below). Animal behaviorists also use mazes to test the learning and memory capabilities of animals. In many cases, such tests will be conducted by placing a food reward at the end of a maze and mice, rats, or other test subjects will be released many times in the maze to see if they make fewer wrong turns with successive tries, as well as reach the reward more quickly.

Classic Mazes

The maze available to you in this exercise is commonly used in experiments to test for animal preferences. It is called a "T-maze," because it is shaped like the letter "T," with the animal starting at the base of the letter and making a choice with a left or right turn at the top arms.



What kinds of questions can you answer with a T-maze? Below are some examples:

- **"Handedness"/"Sidedness":** Does the animal prefer to go to the left or to the right arm or does it visit arms in a particular pattern? Perhaps it goes to alternate arms on successive trials.

- **Simple Learning:** If you place a reward in one arm, how many trials will it take for the animal to go directly to the arm offering the reward? How many runs will it take for it to forget that a reward was offered only in a particular arm, once the reward has been removed? Finally, can you re-establish the preference by bringing the reward back. Will the animal learn more quickly this second time?

- **Preference:** The most common use of the T-maze is to check for preference, asking an animal to choose between two options. Suggested rewards for the maze you have are: shade versus light, moist substrate versus dry, odor versus none (or different odors), different substrate colors, different substrate textures, different food options, food versus no food, etc.

In this exercise, you get to be real scientists, formulating your own hypotheses and designing protocols that will test them. A quick review of **Exercise 1.3** on how science works might come in handy before you start!

Also, remember that testing one individual does not make a scientific study. You can pool the six animals tested in the class if everyone is doing the same experiment, or each group of students could test multiple animals.

- Your class should divide into six groups of students.
- Each group should be given a T-maze.
- Note the size of the track on the maze. You will need to find test subjects that will be able to walk down this groove. Some possible examples include terrestrial isopods (aka roly polies or pillbugs), ants, spiders, small beetles, mealworms, small crickets, etc.
- Wash the track with a paper towel and soapy water. You should then rinse the maze so that no soap residue remains, and dry it before your trial.
- Decide what question you want to ask.
- Obtain all necessary materials for completion of the trials.
- You will probably want to wash the track between each trial to ensure that odor trails left by the individual in one run do not influence its behavior (or the behavior of other individuals) in later runs.
- See if you can answer the following question:

Q1. If you are testing your subject(s) for preference between two options, should you place the two options between which they will choose on the same arm of the maze each time? Why or why not?

NOTE: Your Unit 10 box may have one of several kinds of T-mazes. If you have a container of square plastic tubing and rubber caps, you will need to assemble your T-mazes before use in your trials. To assemble these types of T-mazes, follow the instructions below:

- For a T-maze of this type, you will need two pieces of square tubing (one piece that is only open on both ends, and another that is open on both ends and also with a square hole in the middle of one side), as well as three rubber caps.
- To assemble these T-mazes, insert one end of the tube that is only open on both ends into the square hole on the other piece of tubing.
- You should now have a T-maze that has three openings (one at the end of each "arm", and one opening at the entry point).
  - If you are just testing "handedness," you can then place caps on the openings at the ends of the arms.
  - You can then place the test subject in the entry, and then place a cap on the entry.

- If you are testing for preference and wish to give the test subject two options (food, scents, etc.) from which to choose, you can place these options in the caps for the arms before placing the caps on the ends of the arms, and then introduce the subject into the entry.

Statistical Tests: Evaluating Hypotheses

Let's say, for example, that you are interested in using your T-mazes to address the question of whether a particular species ("species X") of ants in your schoolyard has a preference for one type of sugar (fructose) over another (sucrose). Naturally, you would not feasibly be able to test every individual in the population for their preference. Scientists also almost always face the same predicament in that time, money, and population sizes (among other factors) also prohibit them from collecting data on every individual in populations of interest. However, you could do exactly what scientists do: collect data on a subset, or **sample** of the population (ideally you should be as scientific as possible, and try to make sure your sample is random!). Once you have collected data on trials from a sample of several individuals, however, how would you use these data to further explore this question?

One way that scientists do this is with **statistical tests**, which provide support to (or sometimes fail to support) their hypotheses. You are probably already familiar with the scientific definition of the word **hypothesis** (an "educated guess" based on observations). When testing hypotheses statistically, however, one is actually comparing two different *statistical* hypotheses: the **null hypothesis** and the **alternative hypothesis**. It is important to note that statistical hypotheses are slightly different from scientific hypotheses in that statistical hypotheses simply examine whether there is a difference between groups, or a pattern relating particular variables, but not the WHY behind them.

Back to our ant example, let's say that, based on your observations, that you think that the population of species X in your schoolyard prefers fructose over sucrose. The **alternative hypothesis** (often represented as $\mathbf{H_A}$ or $\mathbf{H_1}$) is simply the original hypothesis formulated by the scientist. For example, your alternative hypothesis in this case would be "the population of ants of species X in our schoolyard displays a preference between fructose and sucrose."

The **null hypothesis** (often represented as $\mathbf{H_0}$) is essentially a hypothesis that is one that opposes your alternative hypothesis. In our example, the null hypothesis would be that "the population of ants of species X in our schoolyard does NOT display a preference between fructose and sucrose."

Null and alternative hypotheses can also have directionality. For example, if you think that the population of species X in your schoolyard prefers fructose over sucrose, the statistical hypotheses that you would be testing would be as follows:

> **H_0:** The population of species X in our schoolyard, on average, prefers fructose over sucrose.
> **H_A:** The population of species X in our schoolyard, on average, prefers sucrose over fructose OR has NO preference between the two sugars.

In conducting statistical hypothesis tests, it is important to realize that what you are doing, ALWAYS, is really testing, based on the sample data, whether you should reject or "fail to reject" the NULL HYPOTHESIS. (*Scientists prefer to say that they "fail to reject" a null hypothesis when doing so is supported by their data, rather than saying they "accept" it, as accepting it implies that the null hypothesis is completely true. However, they know that this very well may not be the case. The null hypothesis may be false, but they may not have enough data to conclusively show that it is false!*)

There are many different types of statistical tests, each of which are used for various types of data, but they all follow the same basic idea:

1. Data are used to calculate a **test-statistic**.
2. The test-statistic is compared to a **critical value** (which depends on the size of the sample, as well as the degree of confidence one wishes to have regarding their decision).
3. The null hypothesis is either rejected or fails to be rejected, based on the comparison of the test statistic to the critical value.

So, how do scientists make informed decisions on population means based only on sample means? Such decisions are based around the concept of **significance**. In other words, your data may appear to reflect an overall preference for one type of sugar over the other, but how likely is it that this difference actually reflects a true preference in the overall entire population? First let's talk a little bit about the types of errors that can be made in statistical tests.

Remember, very often in science, it is impossible to be 100% certain about populations in which we are interested, simply because we cannot measure every individual in the populations. Because of this, there are two different types of errors that we could make based on our data:

1. We could incorrectly reject the null hypothesis when it is true. This is called a **Type I error**.
2. We could incorrectly fail to reject the null hypothesis when it is false, which is known as a **Type II error**.

Dealing with Type II errors is easily solved by gathering as much data as possible. If our sample sizes are large, we are more likely to detect real differences that exist between populations based on our samples. However, scientists deal with Type I errors by deciding how sure they want to be (usually 95%, sometimes 99%; remember, we can never have 100% certainty!) that they are correct in their decision to *reject* the null hypothesis. The value representing the remaining margin of uncertainty (5% or 1%, usually represented in decimal forms as probabilities of 0.05 or 0.01) is known as the **significance level** of the test.

Suppose you find that, in your samples, species X chose fructose 51% of the time, and sucrose 49% of the time. However, is this really significant? Such a small difference may be accounted for by chance alone. Such a small difference could also be a matter of error in your measurements, as perhaps not all of your measurements were done exactly the same way (for example, maybe you might have accidentally gotten the identities of the two sugars mixed up on one or more trials). Thus, chance or error could account for such a small difference, and the population of species X in your schoolyard might not display a preference between the two sugars at all! However, if your data showed that species X chose fructose 90% of the time, and sucrose only 10% of the time, this difference is likely to be a real one, because such a difference is likely too large to be accounted for by chance or error.

Just how large does a difference between sample means have to be to be significant? Well, this depends on how confident we want to be when making statements about the population means, based on our sample means, as well as the sizes of our samples. It is important to note that in science, one can never be 100% confident in the conclusions drawn from characteristics of samples. The only way we can be 100% confident about differences between the means of two different populations would be to measure the value of interest on every single individual in each of the populations we wish to compare, which is often impossible due to limitations of time, money, etc.

Let's return to our "species X/sugar preference" example. Again, if the difference in the proportions of times that each sugar was chosen was very small, our confidence in our ability to say that the population as a whole displays a preference for one sugar over the other is lower than it would be if the difference was fairly large. Also, let's say we ran trials with only five individuals. This is a very small sample. What if this sample, just by chance, contained four individuals that did display a distinct preference, while the population overall truly has no preference (or displays an opposite preference) on average? However, if we ran trials with 100 individuals, and obtained similar results, we would be more confident that these results were significant.

The chi-squared test

In our ant sugar preference example, if we ran trials with multiple individuals, and each time noted which sugar each ant chose (either fructose or sucrose), our data would be an example of **categorical data**. Categorical data are data that represent discrete groups. In this case, the two possible groups (responses) of this variable would be "fructose" and "sucrose". For example, let's say we collected the following data, which we organized into a table showing the number of ants that chose each type of sugar in our T-maze trials.

# of ants that chose fructose	# of ants that chose sucrose
25	**13**

When analyzing categorical data, scientists often use a **chi-squared test**. The chi-squared test (often sometimes just called a "chi-square" test, or sometimes written as "χ^2 test," using the lower case Greek letter "chi") is a statistical test that allows scientists to examine relationships between categorical variables, as well as to compare observed frequencies of particular categorical variables to expected frequencies.

Remember, when conducting statistical tests, you are really testing, based on the sample data, whether you should reject or "fail to reject" the null hypothesis. If we are interested in testing whether the population of ants of species X in the schoolyard have a preference for one type of sugar (fructose or sucrose) over the other, the null hypothesis is that the population, on average, does NOT have a greater preference for one type of sugar, or in other words, prefers both types of sugars equally. This is where the bit about "expected frequencies" we mentioned earlier comes into play. Notice in the data above, there were a total of 38 trials, with *observed* frequencies of 25 for fructose, and 13 for sucrose. If there was no preference for either type of sugar over the other, what would the *expected* frequencies of each be? If you said that the expected frequencies for each would be 19 (equal to 50% of the total number of trials), you are right! Below are our example data of observed frequencies, along with expected frequencies, organized into another table. Organizing observed and expected frequencies into a table in this way is useful when calculating the chi-squared test statistic, which we will explore in a moment.

	# of ants choosing fructose	**# of ants choosing sucrose**
Observed	**25**	**13**
Expected	**19**	**19**

Remember, earlier we said that all statistical tests involve three basic steps, and the first step is the calculation of the test statistic. For the chi-squared test, the test statistic is known as, unsurprisingly, the chi-squared (χ^2). The calculation of the χ^2 is fairly simple, and can be expressed by the following equation:

$$\chi^2 = \sum \frac{(Observed - Expected)^2}{Expected}$$

Expressed verbally, the value of χ^2 is equal to the sum of the squared differences between observed and expected values, divided by the expected value. Often, when calculating the value of χ^2, it is easier if you organize your data into a table like the one below:

Category	**Observed Frequency (O)**	**Expected Frequency (E)**	**(O - E)**	**$(O - E)^2$**	**$(O - E)^2/E$***
Fructose	**25**	**19**	**6**	**36**	**36/19 = 1.8947**
Sucrose	**13**	**19**	**-6**	**36**	**36/19 = 1.8947**
TOTAL	**38**	**38**	**0**	**72**	**χ^2 = 3.78**

*** NOTE: In the final column, you may wish to report the value of $(O - E)^2/E$ to four decimal places to avoid rounding errors when finding the value of χ^2 to two decimal places.**

Again, to calculate the χ^2, essentially all you need to do is to find the difference between the observed and expected frequencies of each category, square this difference, and divide the total by the expected value for that category. Then, add up this resulting value for all categories. In the example using our fictitious ant data above, the value of χ^2 is equal to 3.78.

In the next basic steps of statistical tests, remember that the resulting value of the test statistic is then compared to a critical value, and the results of this comparison are used to help make a decision on whether to reject or fail to reject the null hypothesis.

The critical value in statistical tests varies based on the chosen significance level of the test (usually, 0.05 for most scientific studies), but also based on a number known as the **degrees of freedom**. The concept of "degrees of freedom" is difficult to grasp, and will not be discussed in detail here. However, the *number* of degrees of freedom in a simple one-way chi-squared test (where all you are comparing is observed and expected frequencies of various categories) is simply equal to n - 1, where n is the number of categories. In our example, the degrees of freedom of this chi-squared test equals one (there are two categories: fructose and sucrose, so n=2, and n-1 = 2-1 =1).

The critical value for a chi-squared test at a 0.05 significance level with one degree of freedom is equal to 3.84. When conducting a chi-squared test, if the calculated value of χ^2 is greater than the critical value, you should reject the null hypothesis. However, if the calculated value of χ^2 is less than the critical value, you would fail to reject the null hypothesis.

Returning to our example data, we can see that our calculated value of χ^2 is equal to 3.78, which is *less* than the critical value of 3.84. Because of this, we would fail to reject the null hypothesis (of no preference of one sugar over the other). Thus, even though our data appear to illustrate a trend of a preference for fructose over sucrose in our schoolyard population of ant species X, *the observed differences in our sample between the number of ants that chose fructose and those that chose sucrose are not large enough for us to conclude that the population as a whole, on average, displays a preference for one sugar type.*

Now that you have learned a little about how the chi-squared test works, read the following scenario, and see if you can answer the questions that follow.

A researcher is interested in testing whether a particular species of butterfly prefers certain flower colors over others, and designs an experiment in which a random sample of 120 individuals from a local population are tested 6 times each (for a total of 720 trials) in a radial arm maze that offers 4 choices of colors of realistic simulated "flowers" of the same shape and size. In each trial, the researcher notes the color of the first "flower" that the butterfly approaches. The researcher's data from these trials are shown below.

Color Chosen	Absolute Frequency
Pink	**202**
White	**151**
Red	**193**
Blue	**174**

Q2. State the null and alternative statistical hypotheses that the researcher would address when analyzing these data.

Q3. Construct a table that allows you to calculate the value of χ^2 for this experiment.

Q4. For the researcher's study, the critical value for χ^2 (based on 3 degrees of freedom) is equal to 7.51. Based on your calculation of χ^2 in the previous question, would the researcher reject or fail to reject the null hypothesis? What does this mean?

Exercise 7: Caching Food for Times of Famine

Introduction:

Animals frequently face the problem of feast and famine. That is, there are periods when food is so abundant that an individual could not possibly eat more than a small fraction of what is available to them (the "feast"). And then there may be extended periods when food is scarce (the "famine"). Quite a few animals solve this problem by storing food items for future use. This behavior is called **caching** (pronounced *'cashing'*). Birds, squirrels, and beavers are examples of animals that cache food. Sometimes there is a central cache: that is, the animal stores all of its food in a single place (see Figure 1).

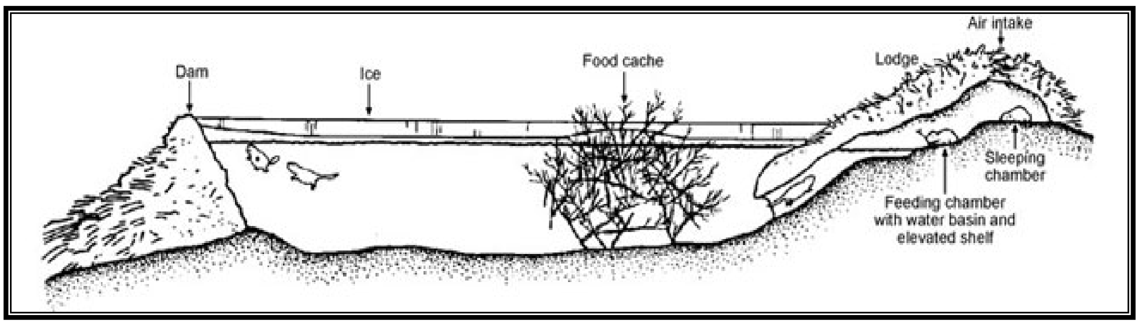


Figure 1. The beaver is an example of an animal that has a single cache.

> *If an animal hides all of its food in the same place and a competitor finds its cache, then the animal will have nothing to eat in times of famine.*

The single cache strategy or tactic is problematic, however, as competitors might find the location of the stash and steal all of the food reserves. Thus, most caching animals have numerous caches, sometimes as many as hundred**s**, scattered throughout their home range (Figure 2). Then, if a competitor finds one of its caches, the animal can still eat food from its other caches. The problem with this strategy, however, is that the animal may have difficulty remembering where it has hidden its food.

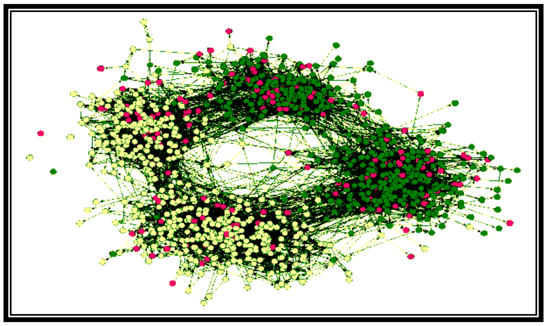


Figure 2. Multiple seed caches for three birds as indicated by respective red, yellow & green dots.

There are three basic ways in which animals relocate multiple food caches to utilize stored food items during periods of food shortage. Each of these relocation tactics is described below:

1. **Episodic Memory:** In utilizing this tactic, the animal remembers hiding each food item, just as you might remember a particular birthday party. When this tactic is used in finding multiple caches, it requires that the animal pay close attention to the path it takes to each cache location from where it has retrieved the food item. Imagine the difficulty of storing all of this information for a bird that has the number of caches shown in Figure 2.

2. **Rule-based Search:** In utilizing this tactic, the individual follows certain rules in hiding its food. A rule-based search typically involves the use of "signposts," such as the placement of food items only under rocks or only on the west side of trees. When performing a rule-based search, the animal only needs to remember the rule/signpost, but it may have to search multiple locations before finding its food. This is because there may be many more signposts (rocks, for instance), in the habitat than those near which the individual cached food.

3. **Re-foraging the Home Range:** No memory is involved in this tactic. Instead, the animal searches the entire home range when looking for a meal during periods of famine. This is an energetically costly food caching strategy.

- Discuss the advantages and disadvantages of each caching tactic, first in terms of whether to have a single cache or multiple caches, and then in terms of the relocation strategy used. Can the environment affect the effectiveness of a tactic? What else could influence the effectiveness of a tactic? Is one tactic always better than the rest?
- Now rank the tactics in a hypothetical order, from best to worst, based on your discussion. You will have four in all (a single cache; and three different multiple cache tactics: episodic memory, rule-based search, and re-foraging the home range). The following exercises will help you to evaluate your rankings, as well as how different traits might provide advantages to organisms in natural systems.

Exercise 7.1: Which Caching Tactic is Best? (*Grades 3-5*)

This is a game for three or four students. One student represents a squirrel who will cache acorns around its home range. The other students in the group will represent "cheaters," or other animals (not necessarily squirrels) that will have a chance to find the caches and steal the acorns before the owner gets a chance to retrieve them. If all of the acorns are not found, then this represents an advantage for the trees in the woodlot, because the unfound acorns will germinate into tree seedlings the following spring.

Instructions:

- While the game is being set up by the caching squirrel, the "cheaters" need to engage in some other task so that they do not see where the is hiding its acorns. The caching squirrel fills the mat with non-overlapping plastic chips of the dominant color without acorns underneath.
- The caching squirrel then decides which caching tactic (i.e. the single cache, or one of the three multiple cache strategies: episodic memory, rule-based search, or re-foraging the home range) he or she will follow, as outlined below:
    - **Single Cache (S):** All acorn chips must be placed in a cluster, with every acorn chip in contact with another acorn chip.
    - **Multiple Caches:** Multiple cache strategies can take three different forms. In all cases, any caching squirrel using a multiple cache strategy

should not place any two acorn chips adjacent to one another. The multiple cache strategies are outlined below:

- **Episodic Memory:** The caching squirrel should replace six random blank chips with acorn chips, and try their best to remember their locations!
- **Rule-based Search:** The caching squirrel should follow a particular rule, with regards to the signpost chips, in placing their acorn chips. Examples include (but are not limited to) "always on the north side of a signpost," "within two chips distance from a signpost," etc. Students with this strategy should be encouraged to be creative in forming their rules, but to make sure to try to remember the rule they used!
- **Re-forage the Home Range:** In this strategy, caching squirrels don't pay attention to where they hide their acorns. Students who draw this strategy should leave their desk and have the teacher (or caching squirrel from another group) hide their acorns for them picture side down.

- Using the chosen caching tactic, the caching squirrel determines the cache locations for the six acorns, removes the non-acorn chips at the spots selected, and places the acorn chips there. Do the same for the four differently colored chips if you want to use them as sign-post chips (the rules-based cache technique). Check to be sure that all chips are picture-side down.
- After the caching squirrel in each group has hidden their acorns, the cheaters should be called back to their groups. Each cheater now gets a chance to turn over one chip. If that chip has an acorn under it, the individual takes the acorn for his or her stash, and can then turn over another chip. This process continues until the first cheater does not find an acorn with a flip.
- The second cheater gets a turn as above, and so on, until all cheaters have had a turn.
- Finally, the caching squirrel gets a chance to search for its caches, using the same protocol as described for cheaters.
- The caching squirrel with the most acorn chips in his/her possession at the end of the game wins, though the trees win if more chips were not found than found.

- Trade places so that the caching squirrel is a cheater and one of the cheaters is the caching squirrel, until all students in each group have had a chance to play the role of a caching squirrel.
- After all students have had the opportunity to play the role of caching squirrels, consider discussing the following topics and conducting further exploration and analysis as a class:
    - Which squirrel (student) had the most successful tactic (resulting in the most chips that they cached)? What tactic did they use?
    - Did students using the same tactic have similar successes in terms of the numbers of acorns they obtained.
    - Were there tactics that were not very successful at all? If so, which one(s)?
    - Construct a bar graph showing the number of acorns recovered by each student when they played the roles of caching squirrels. For further clarity/organization, you may wish to group together bars representing students that used the same tactic.
    - **For 5th grade:** If certain tactics were used by multiple students, there will likely be variation in the number of acorns recovered by those tactics.

For each tactic that was utilized, have students calculate the average number of chips that were recovered when using that tactic. Why do you think there is individual variation in the success of using a particular strategy? How might this influence the overall success of the strategy in the population?

- What do you think would happen to squirrels that use caching tactics that are not very successful? What about squirrels that use more successful tactics?

Exercise 7.2: Factors Affecting Trait Distributions (*Grades 6-12*)

In the fall, squirrels gather and store the mast (acorns) oak trees produce. This provides them with food over the winter and early spring months when it is scarce on the open ground. In this exercise, you will alternately take on the role of a caching squirrel (producer strategy) or that of a scrounger (cheater strategy). Scroungers may be squirrels or other animals that steal the food from the caches they find. (Nature is typically more complex, and a squirrel may play the role of both a cacher and a scrounger to varying degrees.) We will assume for our purposes in this simulation that one individual in a local area is a caching squirrel and the other three individuals are scrounging animals. This experiment is designed to examine the success of the four caching tactics described above. Because scrounger animals are also looking for nuts, the caching squirrel must locate its own nuts while concealing its caching tactic from its competitors. The squirrel that recovers the most of its own cached nuts achieves high reproductive success, referred to as fitness. The following exercises allow you a chance to further explore the concept of fitness, as well as offer you a greater understanding of the process of evolution by natural selection, as well as other factors that can influence trait distributions within populations.

What is fitness? ***Fitness*** (often represented by the variable "***w***") is a measure biologists use to describe an organism's *ability to produce* ***viable*** *offspring based on some trait it possesses* (in this case, a behavioral tactic) that is under selective pressure. (**Viable offspring** are *offspring that reach reproductive maturity*). Fitness is, thus frequently identified as a property of a class of individuals possessing the same trait. The ***absolute fitness*** (w_{abs}) of a particular trait is equal to the ratio of the number of individuals with that phenotype after selection to those before selection (N_{after}/N_{before}). *Absolute fitness is estimated as the product of the survival of individuals possessing a particular trait and average number of offspring contributed by individuals possessing the trait to the next generation.*

Q1. Calculate the absolute fitness for each of the two following traits A and B.

> **Trait A:** Individuals with trait A have a probability of surviving to reproduction of 2/3, and survivors contribute 5 viable offspring to the next generation.
>
> **Trait B:** Individuals with trait B have a probability of surviving to reproduction of ½ and surviving individuals contribute 4 viable offspring to the next generation

- Check your answers in the answer section at the end of this book.

More often, biologists measure how traits (again, in our case, the traits in which we are interested are food storing & recovery tactics) perform relative to other traits. The performance of a trait relative to others is referred to as ***relative fitness*** (**w_{rel}**). This measure *compares the average number of viable offspring produced by individuals possessing a trait to the average numbers of viable offspring of competing traits*. Relative fitness may be calculated using the ratio:

$$\textbf{Relative Fitness (Estimate 1)} = \frac{\textbf{Average N of Trait 1 after selection}}{\textbf{Average N of Trait 2 after selection}}$$

In calculating relative fitness in this manner, if the relative fitness is greater than 1, then the first trait is fitter than the second. If relative fitness is less than 1, then the second trait is fitter than the first.

Typically, however, one sets the trait offering the highest success rate to 1, and expresses other traits as some proportion of 1. This can be done for any particular trait by using the following ratio:

$$\textbf{Relative Fitness (Estimate 2)} = \frac{\textbf{Average N of Trait X after selection}}{\textbf{Greatest N after selection (out of all traits)}}$$

Q2. Based on your calculation of absolute fitness of Trait A and Trait B in Q1, what is the relative fitness of each of these traits? Calculate these values using both methods Estimate 1 & Estimate 2 as described above.

One can use these two estimates of relative fitness to compare a trait of interest to each of the other traits exhibited by individuals in the population. More commonly, we examine trait "success" by comparing the relative frequencies of them graphically over generations of selection. **Relative frequency** refers to the proportion of individuals possessing a particular trait present. It is calculated by dividing the number of individuals possessing a particular trait by the total sum of individuals over all traits:

$$\textbf{\textit{Relative frequency of a trait}} = \frac{\textbf{\textit{number of individuals possessing the trait}}}{\textbf{\textit{total number of individuals}}}$$

- Examine an example of such a graph below in Figure 3. Shown on the graph is the change in the relative frequency of different colored jellybeans after the surviving jellybeans reproduced following selective pressure. *Selective pressure was achieved by having students in an animal behavior class act as predators. Each predator was given the opportunity to choose among the three colors in predating on one bean, which was then consumed. Because the bean did not survive to reproduce, it was lost to the next generation. Surviving beans doubled in number between foraging periods (different classes).* Note that in our jelly bean example, we started out with equal proportions of the three bean colors (33.3%, or an N of 15 each of orange, green, and black colored beans).
- After examining the figure presented below, answer the following questions under Q1 about the selection experiment involving student predation on jellybeans.

Q3. What are the relative frequencies of the three colors at the end of the experiment? How many generations of selection were completed? Which color was preferred by the predators (students) in the experiment? Which color had the greatest fitness?

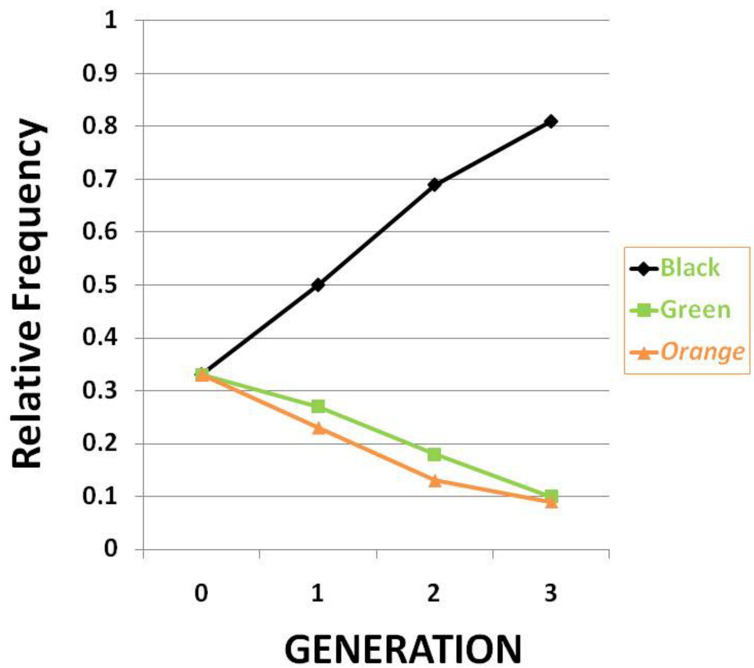


Figure 3. Change in the relative frequency of three colors (phenotypes) and thus flavors (underlying genotypes) of jellybeans under predation pressure by students in an animal behavior class.

Exercise 7.2a: Selection on Caching Tactics (*Grades 6-12*)

In the exercise we will be completing here, our caching squirrels will gather acorns and then hide them according to their caching tactic. We assume that all of these producer squirrels are equally good at gathering acorns, and because there are plenty of acorns to go around, all will hide the same number of acorns (6). However, the caching squirrels may not have equal success in recovering their acorns because of the different tactics they utilized in storing and retrieving them. After the squirrels have finished looking for their acorns, they will reproduce. The more acorns a caching squirrel finds, the more offspring she produces, and thus the fitter she is. (In this game, a caching squirrel produces one offspring for every acorn chip that she recovers.) Finally, we will assume that offspring inherit their mother's caching tactic. Thus, we assume that genes (genotypes) underlie foraging tactics (phenotypes). Each subsequent round of the game represents the following fall (with the new generation of squirrels), and the squirrels gather and hide nuts all over again.

You will play this game several times so that you can measure the absolute fitness of each caching tactic and also observe how the frequency of each tactic changes over time. We will thus be able to produce a graph comparing the success of the different caching strategies over generations of squirrels in this system. To simulate generations you might complete one generation a day or week. We suggest that you complete at least 4 generations in all, though you can learn much in analyzing the results of just the first round.

Initially, the squirrels in the area are equally likely to use any of the tactics, and so the frequencies of the tactics are exactly the same (25% as there are four potential tactics available). Over many generations, however, the frequency of each tactic may change. In our game, these changes simulate the process of natural selection. ***Natural selection*** is the process through which heritable traits that improve an organism's ability to produce viable offspring become more common over time (directional or disruptive selection). Beneficial traits eventually become more common and detrimental ones eventually become less common. Natural selection leads to changes in trait frequencies in populations that are adapting to new selective forces as in ***directional selection*** or ***disruptive selection***. It can also reinforce the prominence of traits providing the greatest fitness in populations that are at adaptive equilibrium (***stabilizing selection***).

Over many generations, natural selection ***can cause beneficial traits to become more common and detrimental traits to become less common.***

- Answer the following questions.

Q4. If populations are at adaptive equilibrium, why does natural selection continue to operate in most contexts?

Q5. Examine the trait distributions before and after selection shown in Figure 4. Try to come up with a consensus as to what type of selection (directional, disruptive/diversifying, or stabilizing) is operating for the graphs in Figures 4A, 4B, and 4C. This will require you to distinguish between directional and disruptive or diversifying selection, something we have not delineated for you. Considering the definitions of these words will help you in discerning which graph is associated with each term.

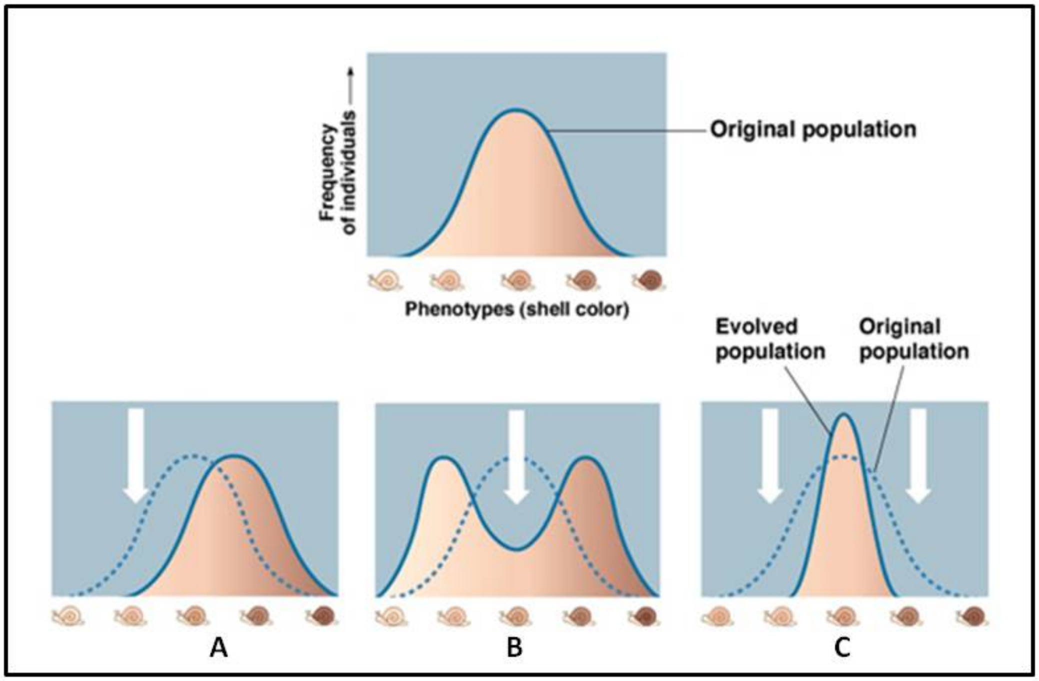


Figure 4. Types of natural selection.

Q6. What potential general evolutionary patterns might you observe in the squirrel caching experiment you are about to complete? (**HINT:** Consult the graph on the previous page showing the relative success of different colors of jellybeans over multiple generations among a population of human predators). By evolution here, we are referring to changes in the frequencies of genes underlying the different caching strategies.

<u>Pre-game Setup for Teachers:</u>

- Photocopy the grids on pages 110 & 111, and cut out each of the lettered squares representing particular caching tactics, and retain these in an envelope or other container. This should take no more than about 30 minutes of prep time. **NOTE:** You may find it helpful to keep the slips of different letters in separate envelopes/containers to keep things organized!
- Also photocopy a number of student data sheet handouts equal to the number of students in your class.
- Open the "***Caching Tactics Over Multiple Generations***" Excel file on the included Teacher CD for this unit, and save a copy of it to your classroom

computer. At this time, you may want to take a few minutes to familiarize yourself with the instructions on the spreadsheet.

- Click the "***Exercise 7.2a***" tab at the bottom of the spreadsheet workbook.
- On your saved copy of the spreadsheet, in the yellow field labeled ***"# of Students***," enter the number of students present in the classroom for that day. You will notice that there is a column labeled "***# of slips***" below the "***Parental Generation***" section in the spreadsheet. Once you have entered the number of students present, you will see that the spreadsheet calculates an equal number of slips for each caching tactic. Take the appropriate number of slips representing each caching tactic, and place them into the drawstring pouch included with the materials for this exercise.

NOTE: For this simulation, it is important that each of the caching strategies be represented equally (with a relative frequency of 0.25) in the parental generation. If your classroom has a number of students that is not divisible by 4, you will also note that a number of "*Extra squirrels needed*" is calculated for you in the spreadsheet. You could allow students to volunteer to play the role of caching squirrels again if they wish to make up these "extra squirrels," or, to participate actively with the class, you could play the role of an "extra squirrel" with as many groups as necessary. (Extra squirrels might also be needed for successive generations, as well, in order to account for rounding of relative frequencies of tactics in each generation, but the spreadsheet will calculate this for you).

<u>Basic Instructions for the Game:</u>

- Divide the class into six groups.
- Each student should receive a copy of the Caching Game (which includes a "home range" mat, 40 blank poker chips of a single color, 6 chips of the same color with an acorn printed on one side, and 4 different colored "signpost" chips), as well as a data sheet for each member in the group.
- One person from each group should be the first "caching squirrel" for the group. All other group members will be scroungers.

- The caching squirrels should go to the teacher's desk, one at a time, to draw a slip of paper with a letter (representing a caching strategy) from the pouch, which has been filled with an appropriate number of slips representing each caching strategy as specified above.
- Upon drawing a strategy, the "caching squirrel" should circle the letter of the caching strategy that they drew from the pouch on their data sheet under the appropriate generation. This data sheet should be kept hidden from the view of all other students! After recording this strategy on their data sheet, the "caching squirrel" should return the slip of paper to the teacher, who will place it to the side (out of the view of other students, but not back into the pouch).
- After the first set of caching squirrels has obtained a caching strategy, they will then spread out the mat in their group's copy of the Caching Game on his/her desk.
- The six chips with acorns printed on one side should be removed from the rest of the chips in the bag, and placed in a stack to the side. The same should also be done with the "signpost" chips of a different color.
- The caching squirrel in each group should now place all remaining 40 blank chips of the main color on his/her mat.
- The caching squirrels will now get a chance to hide their acorns. At this point, the scroungers should be asked to engage in another task or leave the room (i.e. take a restroom break or wait quietly in the hall). The caching squirrels will then remove 4 of the blank chips from their mats, and replace them with signpost chips. They will then hide the acorn chips (acorn side down!) by replacing 6 of the blank chips with acorn chips picture side down, using a procedure appropriate to the caching strategy which they have drawn:
    - **Single Cache (S):** All acorn chips must be placed in a cluster, with every acorn chip in contact with another acorn chip.
    - **Multiple Caches:** Multiple cache strategies can take three different forms. In all cases, any caching squirrel using a multiple cache strategy should not place any two acorn chips adjacent to one another. The multiple cache strategies are outlined on the following page:

    - **Episodic Memory (E):** The caching squirrel should replace six random blank chips with acorn chips, and try their best to remember their locations!
    - **Rule-based Search (R):** The caching squirrel should follow a particular rule, with regards to the signpost chips, in placing their acorn chips. Examples include (but are not limited to) "always on the north side of a signpost," "within two chips distance from a signpost," etc. Students with this strategy should be encouraged to be creative in forming their rules, but to make sure to try to remember the rule they used!
    - **Re-forage the Home Range (F):** In this strategy, caching squirrels don't pay attention to where they hide their acorns. Students who draw this strategy should leave their desk and have the teacher (or caching squirrel from another group) hide their acorns for them.

- After all caching squirrels have hidden their acorns, the scroungers should be called back to their groups. The game then proceeds as follows:
- Each scrounger gets a chance to turn over one chip. If that chip has an acorn under it, the individual takes the acorn for his or her stash, and then can turn over another chip. This process continues until the 1st scrounging squirrel does not find an acorn with a flip.
- The second scrounger then gets a turn as above, and so on, until all scroungers have had one turn. The caching squirrel should keep a running tally of the total number of chips recovered by scroungers.
- The caching squirrel has the last opportunity to search for its caches, using the same protocol as described for the scroungers.
- After the caching squirrel from each group has had their opportunity to recover as many of their cached acorns as possible, they should fill out the following information on their data sheet (still keeping it hidden from the scroungers): the total number of acorn chips the caching squirrel recovered and the number of acorns (if any) not recovered. Each acorn chip recovered by a caching squirrel results in a single offspring being produced to start the next generation. The caching squirrels should then return their data sheets to the teacher.

- The entire procedure above should be repeated, with the previous caching squirrel now taking the role of a scrounger, and one of the previous scroungers becomes the caching squirrel. Repeat this as many times as necessary until all students have had a chance to be a caching squirrel. If there are any leftover slips in the pouch, a few students may be asked to play caching squirrels again, or the teacher may play the role of a caching squirrel with a few groups until all the leftover slips have been removed from the pouch. A separate data sheet should be completed for each caching squirrel.
- You may be asked to now, or during a future class period, to repeat this exercise, only this time representing the next generation of squirrels. Though there were probably more squirrel offspring produced in the last generation than there are students in your class, you will only play the role of a caching squirrel once in each generation (though a few of you, or the teacher, may need to play the role of a caching squirrel more than once). In the simulations of each generation after the parental generation, the relative frequencies of each of the caching tactics represented by the class are very close to, if not exactly the same as the relative frequencies of the tactics' representations in the offspring produced by the previous generation.
- After data have been gathered for several generations, your teacher will compile the raw data for each generation, and provide this information to you. Use this information to fill out the table on page 113, where you will calculate the proportions of reproducing squirrels, birth rates, absolute fitnesses, and relative frequencies of each tactic for each generation.
- Use these data to produce a graph illustrating the relative frequencies of each caching tactic over all of the generations that you simulated, and discuss, as a class, the following questions:
    - What kinds of trends do you notice in the relative frequencies of each caching tactic over time?
    - Do these trends support your hypothesized "best to worst" rankings of each of the caching tactics?
    - If these results seem contradictory to your hypothesized rankings, how do they differ? What possible explanations can you think of that might explain any differences?

  - Interpret your results in light of selective pressures. For instance, how much of a particular tactic's lack of success reflected the inability of the caching squirrel to relocate its stored resources versus the ease with which the resources were found by scroungers?
  - In this exercise, selective pressure (in the form of scroungers trying to rob your stash) was the only substantial factor contributing to changes in relative frequencies of each tactic over multiple generations. Can you think of any other factors, aside from selective pressure, that could influence the relative frequencies of each caching tactic over time?

Notes on Data Compilation for Teachers:

- Below is information on how to fill out the provided Excel spreadsheet:
  - Under the "***# Reproducing***" column, you should enter the number of squirrels of each tactic that successfully found at least one acorn chip during the parental generation.
  - Under the "***Total # Offspring***" column, simply enter the total number of offspring produced (total number of acorn chips recovered) by all individuals using each caching tactic.
- You will notice that when you input these data, numbers of slips of each tactic to place in the pouch at the beginning of the following generation (make sure the pouch is empty first!), as well as the number of "extra squirrels" needed, if any, are calculated for you. Make sure to save your data after entering them for each generation, to use as a guideline for subsequent generations, as well as to have a basis from which to evaluate student answers!

NOTE: The full results after each generation should be kept hidden from students until the completion of all generations. Otherwise, in each round, clever scroungers will likely take note of the most common tactic, and adopt that tactic in their scrounging, resulting in negative frequency dependent selection (also known as balancing selection), in which the most common phenotype is selected against, usually resulting in a balanced mix of phenotypes (which would be similar to the parental generation, and thus failing to illustrate substantial change in relative frequencies in this exercise).

Exercise 7.2b: Interactions Between Selection & Drift (*Grades 6-12*)

In the previous exercise, the resulting relative frequencies of the various caching tactics in your squirrel populations changed primarily due to selective pressures (the presence of scroungers) alone. However, in this exercise, the instructions differ slightly, allowing you to more clearly see a more realistic view of how other factors can affect relative frequencies of traits and trait distributions within populations.

In the real world, trait frequencies may not change in the ways one might expect, despite the fact that natural selection is occurring. Random events can force traits into extinction, and once a trait has been eliminated from the population, its frequency cannot increase. Such random effects are known as ***genetic drift***. For example, imagine that a fire broke out in the forest where our squirrels lived, and only a small proportion of squirrels survived. The frequencies of the caching strategies of survivors is highly unlikely to be the same as the frequencies of caching strategies present in the initial population, and by chance, the squirrels with the "best" caching strategy in the initial population could be wiped out entirely in the fire.

Random variations that cause unexpected changes in trait frequencies are called genetic drift**.**

Such effects, however, tend to most influence traits that are initially present in low frequencies due to prior selection against them. However, individuals dispersing from a population that has exceeded its ***carrying capacity*** (or individuals that are otherwise displaced into new areas distant from the initial population), may start a new population that has a different trait frequency distribution. These dispersers can produce genetic drift through sampling error, also known as the ***founder effect***.

In this version of the game, each year, some of squirrel offspring may not survive to reproduce, because the forest where these squirrels live has a ***carrying capacity*** of a number, ***K***, of squirrels (predetermined by your teacher). This means that the forest can support at most ***K*** squirrels, and so any squirrels in excess of this number must compete against each other for survival. After a particular generation produces offspring, if the total number of offspring produced is greater than the forest's carrying capacity, the individuals in excess of the carrying capacity will die, at random, before reaching reproductive maturity. The offspring that survive until the next year are viable, that is, they will have the opportunity to reproduce.

The probability that a squirrel survives depends on the number of squirrels born that year. If a number of squirrels less than or equal to ***K*** are born in a year, then the probability that a squirrel survives is equal to 1. If more than ***K*** squirrels are born in a year, then the probability that a squirrel survives is equal to ***K*** divided by the number of squirrels born that year.

Q7. Suppose that the entire squirrel population with a carrying capacity of 28 recovers 26 acorn chips. What is the probability that one of these offspring survives to the next year? What is the probability that a squirrel survives if the population recovers 100 acorns?

Q8. What happens to the probability that a squirrel survives to the next year as the number of offspring born increases?

Setup Notes for Teachers:

- Open the "***Caching Tactics Over Multiple Generations***" Excel file on the included Teacher CD for this unit, and save a copy of it to your classroom computer. At this time, you may want to take a few minutes to familiarize yourself with the instructions on the spreadsheet.
- Click the "***Exercise 7.2b***" tab at the bottom of the spreadsheet workbook.
- On your saved copy of the spreadsheet, in the yellow field labeled "***# of Students***," enter the number of students present in the classroom for that day. Notice that the spreadsheet will then calculate the ***carrying capacity*** for your squirrel population, how many slips of each tactic to put in the included pouch before simulating the parental generation, as well as (if necessary) a number of "***Extra Squirrels Needed***," as in the previous exercise. Take the appropriate number of slips representing each caching tactic, and place them into the drawstring pouch included with the materials for this exercise.

The number of individuals of a single species that an environment can support is called the environment's **carrying capacity** *for the species.*

- Each student should be provided with a blank grid (template on page 115), as well as a data sheet (on page 112). Each group of students should also have a pair of scissors.

Instructions for Students:

- The parental generation will be simulated in a manner identical to that in Exercise 7.2a:
    - One person from each group will be selected to act as a caching squirrel. Each caching squirrel will then draw a slip representing a caching strategy from the pouch, record this on their data sheet (keeping this hidden from other students), and return the slip to the teacher, who will place it in a location separate from the remaining slips in the pouch.
    - Individuals acting as scroungers in each group will be asked to leave the room while caching squirrels hide their acorns according to the tactic they drew from the pouch.
    - The scroungers will be called back, with each scrounger getting a turn to flip over one chip on the home range. If an acorn is revealed, the scrounger gets to flip another chip. However, if the chip flipped is blank, that scrounger's turn ends.
    - All scroungers will get a chance to forage for acorns first, and then the caching squirrel gets his/her turn. Caching squirrels should, as before, record on their data sheets the number of acorns they recovered (representing the number of offspring they produced), the total number of acorns recovered by scroungers, and the total number of acorns not found.
    - This should now be repeated, with the previous caching squirrels becoming scroungers, and one of the previous scroungers becoming a caching squirrel, until all students have played a caching squirrel for the parental generation. If there are any leftover slips in the pouch, a few students may be asked to play caching squirrels again, or the teacher may play the role of a caching squirrel with a few groups until all the leftover slips have been removed from the pouch. A separate data sheet should be completed for each caching squirrel.

- At this point, the instructions change slightly. First, the teacher should make sure that the tactic pouch is empty of any scraps of paper. After all students have had a chance to simulate a caching squirrel in the parental generation, each of you should cut out a number of blank squares from your grid equal to the number of offspring you produced (the number of acorn chips you recovered) as a caching squirrel. On each of these blank squares, you should write the letter representing the caching tactic you used (single cache = **S**, episodic memory = **E**, rule-based search = **R**, and re-forage the home range = **F**). Each of these slips should be placed into the pouch. Any students (or the teacher) playing the role of any extra squirrels should make sure they do this for each squirrel they represented in the parental generation!

Though there may be many "offspring" in the "pool" for the next generation, *remember that only a number equal to the carrying capacity will survive to reproductive maturity.* ***To simulate this fact in each successive generation, the game will be repeated as earlier,*** *but with only a number of slips equal to the carrying capacity being drawn from the pouch to begin each new generation.* ***These slips represent the individuals that actually survived to reproductive maturity, and who will contribute offspring to the pool for the next generation.***

- After all students have added their "offspring" (their slips of paper) to the "pool" of offspring for the next generation (the pouch), the pouch should be shaken to mix the paper squares.
- To start the next generation, you will simply repeat the procedure above:
    - One caching squirrel from each group will draw a caching strategy slip from the pouch, noting the caching strategy that they drew on their data sheet (keeping this data hidden from other students).
    - Scroungers from each group will be asked to leave the room while the caching squirrels hide their acorns according to the caching strategies they drew.
    - Scroungers will be called back and allowed their chance(s) to flip chips, getting to flip another if an acorn chip is recovered, but moving to the next scrounger when a blank chip is flipped. Finally, the caching squirrel will get a chance to recover any remaining acorn chips as above.

- After the caching squirrel's turn, the caching squirrel should record the number of acorn chips they recovered, the total number of acorn chips recovered by scroungers, and the total number of acorn chips not recovered beside the appropriate generation on their data sheets.
    - The previous caching squirrel should now become a scrounger, with one of the previous scroungers now becoming a caching squirrel. This should be repeated until all students have had a chance to be a caching squirrel at least once (some students may need to be a caching squirrel more than once, or the teacher may play the role of a caching squirrel with one or more groups), until a total number of slips equal to the carrying capacity have been drawn.
    - All students should now cut out a number of blank squares from their grid equal to the number of acorn chips they recovered on their turn(s) as a caching squirrel. The tactic pouch will be emptied, and caching squirrels will now add their offspring to the pool of individuals for starting the next generation.
- For the final generation simulated, students do not have to complete the foraging attempts, and simply need to note the caching tactic they drew on their data sheets.
- After all students have completed their data sheets, these should be submitted to the teacher, who can compile the data for each generation, and provide these data to students for further analysis and graphical representation.
- After you are provided with the pooled data from the teacher, use this information to complete the data table for Exercise 7.2b.
- Produce a graph of the relative frequencies of each caching tactic over the generations you simulated.
- Compare this graph to the graph you produced in Exercise 7.2a, and discuss the following questions:
    - Did the graphs of the relative frequencies of each tactic show similar trends?
    - If there are differences between the two graphs, what factors do you think contributed to these differences?
    - If you repeated Exercise 7.2a several times, would you expect to see the same trends as observed in your original graph from Exercise 7.2a?

What about Exercise 7.2b? Which of the two exercises would you expect to show more variation in trends of relative frequencies of each caching tactic, and why?

Template for Caching Strategy Slips for Exercise 7.2a (page 1 of 2)

S	S	S	S	S	S
S	S	S	S	S	S
S	S	S	S	S	S
S	S	S	S	S	S
S	S	S	S	S	S
S	S	S	S	S	S

E	E	E	E	E	E
E	E	E	E	E	E
E	E	E	E	E	E
E	E	E	E	E	E
E	E	E	E	E	E
E	E	E	E	E	E

Template for Caching Strategy Slips for Exercise 7.2a (page 2 of 2)

R	R	R	R	R	R
R	R	R	R	R	R
R	R	R	R	R	R
R	R	R	R	R	R
R	R	R	R	R	R
R	R	R	R	R	R

F	F	F	F	F	F
F	F	F	F	F	F
F	F	F	F	F	F
F	F	F	F	F	F
F	F	F	F	F	F
F	F	F	F	F	F

Student Data Sheet for the Caching Game (use for both Exercises 7.2a & 7.2b)

Student Name: ________________________ **Exercise (circle one):** 7.2a 7.2b

Parental Generation

Caching Tactic (circle the one you used)	Number of Acorn Chips You Recovered	Number of Acorn Chips Scroungers Recovered	Number of Acorn Chips Not Found
S E R F			

Generation 1

Caching Tactic (circle the one you used)	Number of Acorn Chips You Recovered	Number of Acorn Chips Scroungers Recovered	Number of Acorn Chips Not Found
S E R F			

Generation 2

Caching Tactic (circle the one you used)	Number of Acorn Chips You Recovered	Number of Acorn Chips Scroungers Recovered	Number of Acorn Chips Not Found
S E R F			

Generation 3

Caching Tactic (circle the one you used)	Number of Acorn Chips You Recovered	Number of Acorn Chips Scroungers Recovered	Number of Acorn Chips Not Found
S E R F			

Generation 4

Caching Tactic (circle the one you used)
S E R F

Student Data Table for Exercise 7.2a: Selection on Caching Tactics

NOTES: Simulation of foraging bouts is unnecessary for the 4th generation, as the relative frequencies in the final generation can be obtained from the number of offspring produced by the next to last generation. In column **G** ("***Relative Frequency***"), the relative frequencies of parental phenotypes should be calculated from the initial numbers of simulated "squirrels" in the parental generation. However, for consistent and more accurate relative frequencies in subsequent generations, use the total numbers of offspring produced by the previous generation.

Caching Tactic	**Gen**	**A** **# of Squirrels Using this Tactic**	**B** **# of Squirrels Producing ≥ 1 Offspring**	**C** **Proportion Producing ≥ 1 Offspring** = B/A	**D** **Total # of Offspring** = total # acorn chips found by that tactic	**E** **Birth Rate** = D/A	**F** **Absolute Fitness** = C x E	**G** **Relative Frequency** for parents, use A/sum of all parental A; for future generations, use D from previous gen/sum of all D produced by the previous generation
Single Cache	0 (parental)							
	1							
	2							
	3							
	4							
Episodic Memory	0 (parental)							
	1							
	2							
	3							
	4							
Rule-based Search	0 (parental)							
	1							
	2							
	3							
	4							
Re-forage Home Range	0 (parental)							
	1							
	2							
	3							
	4							

Student Data Table for Exercise 7.2b: Effects of Selection & Drift on Caching Tactics

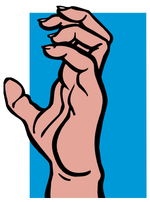
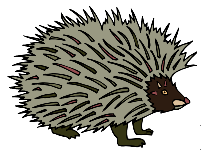
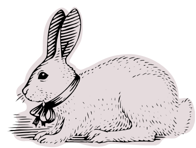
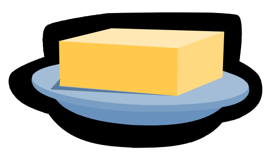
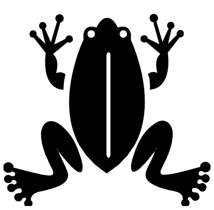
NOTES: Simulation of foraging bouts is unnecessary for the 4th generation, as the relative frequencies in the final generation can be obtained from the number of individuals drawing each tactic at the beginning of the 4th generation. In column D ("***Probability of Survival***"), this value is equal to 1 if the total number of offspring for all tactics is less than or equal to ***K***. Otherwise, this value is equal to ***K*** divided by the total number of offspring produced by all tactics. In column **G** ("***Relative Frequency***"), the relative frequencies of each tactic is calculated as the number of individuals drawing that particular tactic at the beginning of that generation, divided by the total number of squirrels (which will be less than or equal to ***K***) at the beginning of that generation.

Carrying Capacity ***K*** = ____		**A**	**B**	**C**	**D**	**E**	**F**	**G**
Caching Tactic	Gen	**# of Squirrels Using this Tactic**	**Total # of Offspring** = total # acorn chips found by that tactic	**Birth Rate** = C/A	**Probability of Survival** See above notes	**Absolute Fitness** = C x D	**Relative Fitness** = C x E	**Relative Frequency** See above notes.
Single Cache	0 (parental)							
	1							
	2							
	3							
	4							
Episodic Memory	0 (parental)							
	1							
	2							
	3							
	4							
Rule-based Search	0 (parental)							
	1							
	2							
	3							
	4							
Re-forage Home Range	0 (parental)							
	1							
	2							
	3							
	4							

Blank Caching Strategy Slip Template for Exercise 7.2b

ANSWERS FOR EXERCISE 1

Tactile Box Chart

Outside Picture	Inside Texture
 **Hand / Claws**	 **Rough / Prickly**
 **Foot**	 **Soft / Fluffy**
 **Flower**	 **Bumpy**
 **Butterfly**	 **Smooth**
 **Frog**	 **Sticky**

Answers for Exercise 1.3a

Examples of hypothesis testing procedures

Procedure 1: Testing for each object separately

- First, place one object at a time in the white box tin and observe how the object alters the tin's characteristics. For example, you might note how heavy the tin feels with the object inside it. If you have a scale you could even weigh the tin with the object inside it. You could test to see if the magnet attracts the object through the tin. You could also try shaking the tin to see if the sound is loud or soft, sharp or dull. Try to think of other ways to examine the tin. Record your observations in a table like Table 1.

Table 1: The characteristics of the white box tin when it contains one object:

object	sound	weight	magnet
crayon			
paper clip			
marble			
cotton ball			
rubber ball			
penny			
poker chip			
cork			
toothpick			
metal ball			
rubber band			

- What is in the black box tin? Since there are only eleven possible objects, you can test the tin for each of them. This means that you will test eleven hypotheses of the form: "There is a ______ in the tin."
- For each hypothesis complete the following steps:

  1) Use your table of observations to form predictions about what characteristics the tin should have if the hypothesis is true. For example, if your hypothesis is: "There is a marble in the black box tin," and you observed that the marble made a sharp metallic sound in the white box tin, then one of your predictions might be

that the black box tin will make a sharp metallic sound when you shake it.

2) Experiment with the black box tin to see if it satisfies your predictions.
3) If the black box tin fails to satisfy a prediction, then you can reject the hypothesis that you are testing, eliminate the hypothesized object from the list of possible objects, and begin to test a new hypothesis. Continuing with the example above, if you shake the black box tin and hear ***only*** a dull thud, then you should eliminate the marble from the list of possible objects and begin to test a new hypothesis.
4) If the black box tin satisfies all of your predictions, then the object you hypothesized was in the box should remain on the list and you can begin to test a new hypothesis.

- Continue to test the black box tin until you have tested it for each of the eleven objects.
- If more than two objects remain on your list of possibilities, you may want to think of some new experiments that could help you to eliminate more objects from the list.
- Once you have eliminated as many objects as you can from the list of possibilities, select two of the remaining objects as your final hypothesis.

Procedure 2: Testing the tin for each pair of objects

- Examine the weight, sounds and other characteristics of the black box tin, and record your observations in a table like Table 2.

Table 2: The characteristics of the black box tin

sound	weight	magnet

- What is in the black box tin? In this procedure you will test all possible pairs of objects to see if they are the pair that is in the black box tin. This means that you will test fifty-five hypotheses of the form: "There is a _____ and a _____ in the black box tin."
- For each hypothesis complete the following steps:

1) Place the pair of objects that you hypothesize are in the black box tin box into the white box tin.
2) If your hypothesis is true, then the white tin box should now have the same characteristics as the black box tin, therefore you should predict that the white box tin will now have all of the characteristics that are listed in your table of observations. For example, if your hypothesis is: "There is a cork and a cotton ball in the black box tin," and you observed that the black box tin made a sharp metallic clink when you shook it, then one of your predictions might be that the white box tin will now also make a sharp metallic sound when you shake it. *Note that in this procedure your predictions are the same for each hypothesis.*
3) Experiment with the white box tin to see if it satisfies your predictions.
4) If the white box tin fails to satisfy any of your predictions then you can reject the hypothesis that you are testing, eliminate the hypothesized pair from the list of possible pairs, and begin to test a new hypothesis. Continuing with the example above, if you shake the white box tin and hear ***only*** a dull thud, then you should eliminate the cork and cotton ball from the list of possible pairs and begin to test a new hypothesis.
5) If the black box tin satisfies all of your predictions ,then the pair that you hypothesized was in the black box tin should remain on the list, and you should begin to test a new hypothesis.

- Continue to test the tin until you have tested it for each of the fifty-five pairs of objects.
- If more than one pair remains on your list of possibilities, you may want to think of some new experiments that could help you to eliminate more pairs from the list.
- Once you have eliminated as many pairs as you can from the list of possibilities, select one of the remaining pairs as your final hypothesis.

Answers for Exercise 1.3b.1

Q1. What is the probability of spherical (ball-shaped) object being in the Black Box? Express this probability as a fraction, a decimal, and a percent. Remember, all of these values mean exactly the same thing!
Since there are four spherical objects (cotton ball, marble, metal ball, and rubber ball) out of 11 total possible objects, the probability that there is a spherical object in the Black Box is equal to 4/11 (which is approximately equal to 0.36, or 36%).

Q2. What are the odds of a spherical object being in the Black Box?
The odds of a spherical object being in the Black Box are 4:7.

Q3. If you were to simply guess the identity of the object in your Black Box without using any of the steps of the scientific method, what would be the probability that you got the answer correct?
If you were to simply guess the identity of the object in the Black Box without using the scientific method, the probability that you would be correct would be equal to 1/11 (which is approximately equal to 0.09, or 9%). Hopefully the proportion of groups that guessed the correct object by using the scientific method is larger than this!

Answers for Exercise 1.3b.2

Q4. Suppose that you roll a six sided die. Let *E* denote the event that you roll less than a five. Write down all of the elements that belong to the event *E*.

$$\{1,2,3,4\}$$

Q5. Let *B* be the event that you roll $1, 4$, or 6, that is, let $B = \{1, 4, 6\}$. Are *B* and *E* mutually exclusive? If not, which elementary events belong to both *B* and *E*?
B and *E* are not mutually exclusive, because both of them contain the elementary events $\{1\}$ and $\{4\}$.

Q6. Suppose two coins are tossed. Let *A* be the event that the first coin is heads, and *B* be the event that the second coin is heads. Are *A* and *B* independent?
Events *A* and *B* are independent, because the flip of one coin has no effect on the result of the flip of the other.

Q7. Suppose that two children attend the same daycare. Let *A* be the event that the first child catches a cold and *B* be the event that the second child catches a cold. Are the events *A* and *B* independent?
In this case, events *A* and *B* are not independent. Since the students are in the same school, exposure to the first child, who has a cold, increases the probability that the second child catches a cold.

Q8. Suppose that you have a marble, a metal ball, and a penny. Imagine that you form a pair by choosing two objects from this set. How many ways can you form a pair?
There are six ways to form a pair if we consider the order that the objects are added: marble and metal ball, marble and penny, metal ball and penny, penny and metal ball, penny and marble, metal ball and marble.

Q9. How many distinct pairs can be formed from the three items above?
You should have noticed that though there are six different ways to form pairs from the three objects if order is considered, when only the identities of the objects are considered, there are only three distinct pairs of objects, as each unique pair is duplicated.

Q10. How many pairs in our Black Box experiment are in an event that has a penny?
Every object that isn't a penny can be used to make a pair with a penny. Since there are ten objects that are not pennies, there are ten pairs that have a penny: {penny, poker chip}, {penny, rubber ball}, {penny, rubber band}, {penny, metal ball}, {penny, marble}, {penny, tooth pick}, {penny, paper clip}, {penny, cotton ball}, {penny, cork}, {penny, crayon}.

Since there are ten pairs that have a penny, and 55 possible pairs, the probability that you choose a pair with a penny is:

$$\frac{\mathbf{10}}{\mathbf{55}} = \frac{\mathbf{2}}{\mathbf{11}}, \boldsymbol{which\ is\ approximately}\ \mathbf{0.18}, \boldsymbol{or}\ \mathbf{18\ in\ 100\ guesses}$$

Q11. What is the probability that your Black Box has a pair consisting of a penny or a marble, but not both a marble and a penny?
Since there are nine pairs that contain a penny but do not contain a marble, and nine pairs that contain a marble but do not contain a penny, there are eighteen pairs in this event. Since there are 55 possible pairs, the probability that this event occurs is $\frac{\mathbf{18}}{\mathbf{55}}$

$$= \boldsymbol{approximately}\ \mathbf{0.33}, \mathbf{or\ 1\ out\ 3\ guesses}.$$

Q12. What is the probability that, by guessing alone, you correctly guess the identity of one (but not both) of the objects in your Black Box?

This is simply a generalization of **Q11**. Since the presence of a particular object in the tin is random with respect to other types of objects, the probability that you find a pair that contains one of the objects in your tin but not the other object of interest is the same as the probability that you find that you have a pair of objects in your tin with a marble or a penny, but not both, or

$$\frac{\mathbf{18}}{\mathbf{55}} \approx \mathbf{0.33}, \textbf{ or 1 out 3 guesses}.$$

Q13. Fill in the following table regarding the number of possible shakes and cones in our hypothetical ice cream shop:

# of Scoops	# of possible shakes (no flavor duplication)	# of possible shakes (duplication allowed)	# of possible cones (no flavor duplication)	# of possible cones (duplication allowed)
1	5	5	5	5
2	10	15	20	25
3	10	35	60	125
4	5	70	120	625
5	1	126	120	3125

Q14. Regarding the Black Box experiment, are your hypotheses more related to combinations or permutations? Why?
Your hypotheses are more related to combinations, because you are only interested in determining the identities of the mystery items in the Black Box, not the order in which the pair of items was placed into the box.

Q15. Using what you now know about combinations and permutations, and the fact that there is NO duplication of objects in the Black Box, calculate the number of different pairs of 11 objects from the White Box that could be placed into a Black Box.
Since the order in which the objects of a pair are placed into the box does not matter (all we are interested in is *which* pair of items is in the box), and we know that duplication is not allowed, we can use the formula for calculating the number of possible *combinations* with no duplication to find this answer:

$$\frac{\boldsymbol{n}!}{(\boldsymbol{n}-\boldsymbol{r})!\,(\boldsymbol{r}!)} = \frac{\mathbf{11}!}{(\mathbf{11}-\mathbf{2})!\,(\mathbf{2}!)} = \frac{\mathbf{11}!}{(\mathbf{9})!\,(\mathbf{2}!)} = \frac{\mathbf{11}\times\mathbf{10}\times\cancel{\mathbf{9}\times\mathbf{8}\times\mathbf{7}\times\mathbf{6}\times\mathbf{5}\times\mathbf{4}\times\mathbf{3}\times\mathbf{2}\times\mathbf{1}}}{(\cancel{\mathbf{9}\times\mathbf{8}\times\mathbf{7}\times\mathbf{6}\times\mathbf{5}\times\mathbf{4}\times\mathbf{3}\times\mathbf{2}\times\mathbf{1}})(\mathbf{2}\times\mathbf{1})}$$

$$= \frac{110}{2} = 55\ possible\ pairs\ of\ objects$$

Q16. Since the pairs of items placed into a Black Box are determined at random, what is the probability that there is a marble and a cork in any given Black Box?

The probability that there is a marble and a cork in any given Black Box is equal to

$$\frac{1}{55} \approx 0.018 \approx 1.8\%$$

Q17. What if you were given a Black Box and told that there were three items in the box (with the same restriction of no identical items). What would be the probability of correctly guessing *all three* items in the box without using the any elements of science, and without any contact with the Black Box whatsoever?

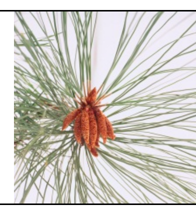
$$\frac{n!}{(n-r)!\,(r!)} = \frac{11!}{(11-3)!\,(3!)} = \frac{11!}{(8)!\,(2!)} = \frac{11 \times 10 \times 9 \times \cancel{8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1}}{(\cancel{8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1})(3 \times 2 \times 1)}$$

$$= \frac{990}{6} = 165\ possible\ combinations\ of\ three\ objects$$

ANSWERS FOR EXERCISE 2

Answers for Exercise 2.1: How good is your nose?

Answers for Exercise 2.1a: Coarse Level Discrimination

		
B1: Cinnamon	**B2: Fish**	**B3: Pine**
		
B4: Fruit	**B5: Coffee**	**B6: Licorice**

Answers for Exercise 2.1b: Fine Level Discrimination

		
R1: Strawberry	**R2: Peach**	**R3: Pear**
		
R4: Banana	**R5: Orange**	**R6: Lemon**

Answers for Exercise 2.2: Find That Flower I

Flowers have evolved fragrances or scents that attract animals that vary in their sensitivity to them.

1. Bees are attracted to what humans would call sweet or spicy scents. Because we can detect these scents and they register as pleasant to us, many perfumes are similar in scent to the flowers bees are attracted to. We refer to these perfumes as floral in nature as the person wearing one smells a bit like a florist shop

2. Flies unlike bees are attracted to odors that are not very pleasant to humans. As they lay their eggs (oviposit) on rotting flesh and dung, plants that emit similar odors attract them.

3. Butterflies and birds are not very olfactory. They are much more visual in behavior. Thus, your butterfly did not do very well in locating the target flower. That is, unless this particular student had an unusually acute sensitivity to the odor emitted by a cotton ball!

ANSWERS FOR EXERCISE 3

Answers for Exercise 3.1: Find That Flower II

One of the flowers has a funnel that guides the insect's proboscis (straw) to the nectar source. Most flowers have not only petals shaped in a funnel but also nectar guides, lines or color patterns that radiate out from the source of the nectar reward. These lines are like the painted lines on a runway guiding a plane down to an airport. The anthers will be located above the funnel or below the legs of the insect standing on the landing platform such that pollen will stick to the legs for transport to other flowers of the same species. See pictures below.

Nectar Guides

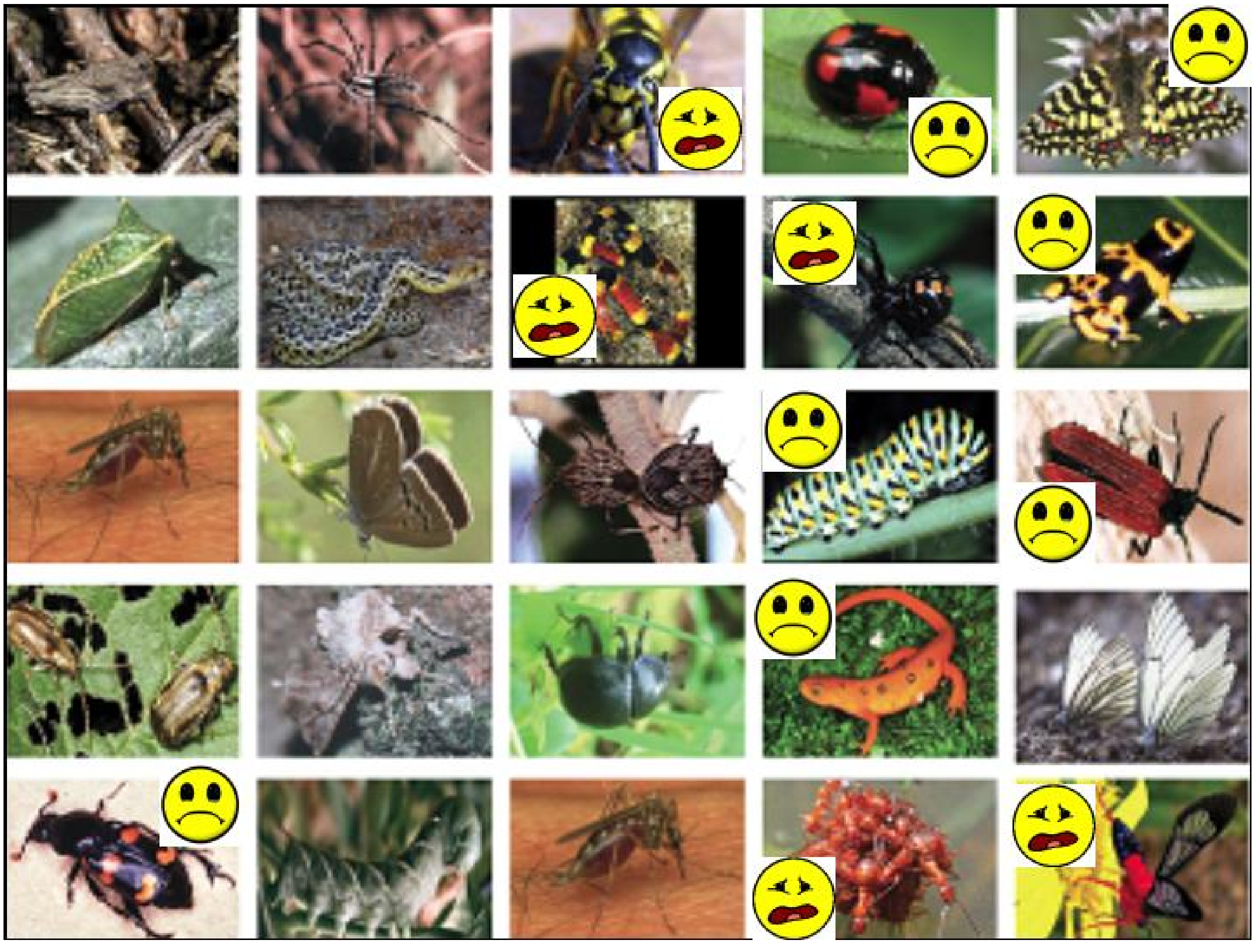
Pollen Transfer Sequence

1.Pollen grains on anthers of stamens

2. Bee collecting nectar & pollen accidentally on legs

3. Bee bringing pollen on leg in to new flower it will collect nectar from.

Answer Key for Exercise 3.2a Slap Snack Alarm



Answers for "The Advantage of Good Vision to Predators"

Q1. If you can't see well and must choose your prey card at random, what is the probability that you will choose a good card?
The probability that a card chosen at random is a good card is equal to 13/25 = 0.52 = 52%.

Q2. Is the probability from Q1 better or worse than if you were to toss a coin?
The probability of choosing a good card at random from the Alarm deck is slightly better than the probability of correctly calling the toss of a coin.

Q3. Luckily, you can see very well. When you played the game, what percent of the cards that you chose did you get right? Was this better than your probability if you had to choose prey at random? How is having good vision a survival advantage for predators? Justify your answer.

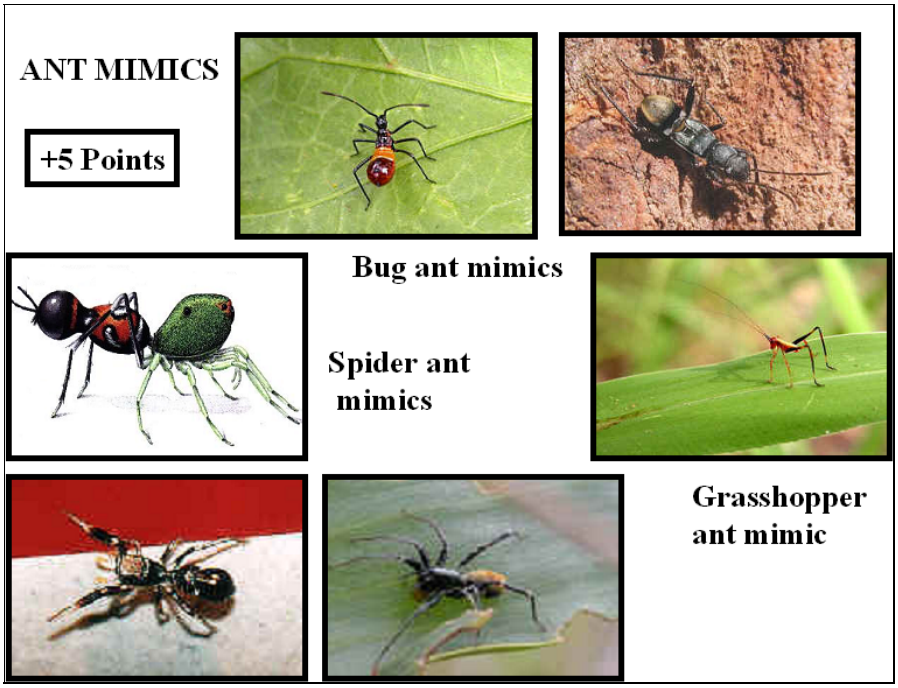
Student answers to this question will vary, but after the introduction on aposematic coloration of chemically defended prey, most students will have likely gotten a higher percentage of "good" cards than that expected by chance alone (if they had simply randomly slapped/"eaten" prey item cards). Good vision is an advantage for predators, because being able to correctly identify potential prey as either nutritious or harmful directly influences a predator's chance for survival.

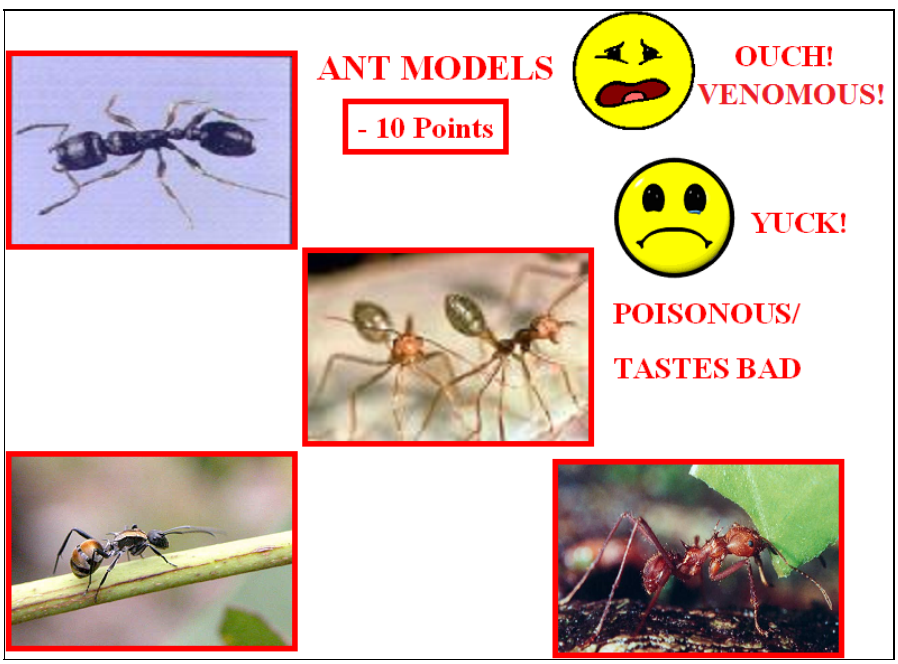
Q4. Explain how competition with other predators when you played the game may have affected the ratio of your success.

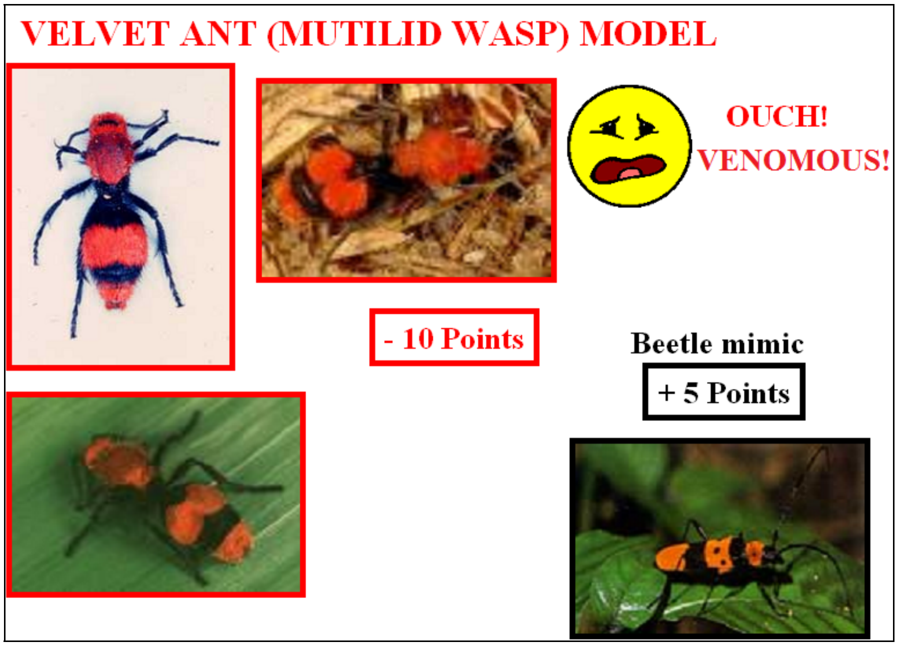
Competition with other "predators" likely reduced your ratio of success. Since other predators were also simultaneously pursuing the limited prey resource, the pressure of competition might cause predators to quickly accept prey items without considering whether the prey might be chemically defended as carefully as they would have if other predators were not actively foraging for the same resources at the same time. Also consider the fact that in addition to the ratio of success, the "food reward score" obtained by each predator is important, as a greater food reward score means that the predator gathered more valuable food resources, which means more energy for growth and reproduction for that predator. Competition also decreases the overall average number of "nutritious" prey available per predator, also resulting in a smaller possible food reward score on average, for each predator.

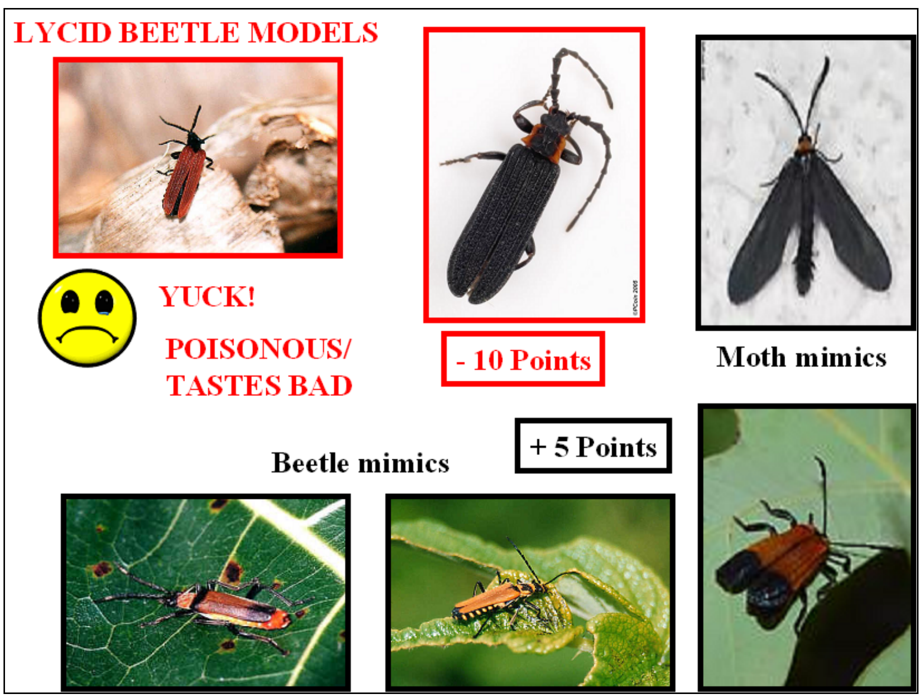
Answers for Exercise 3.2b: Slap Snack Mimic

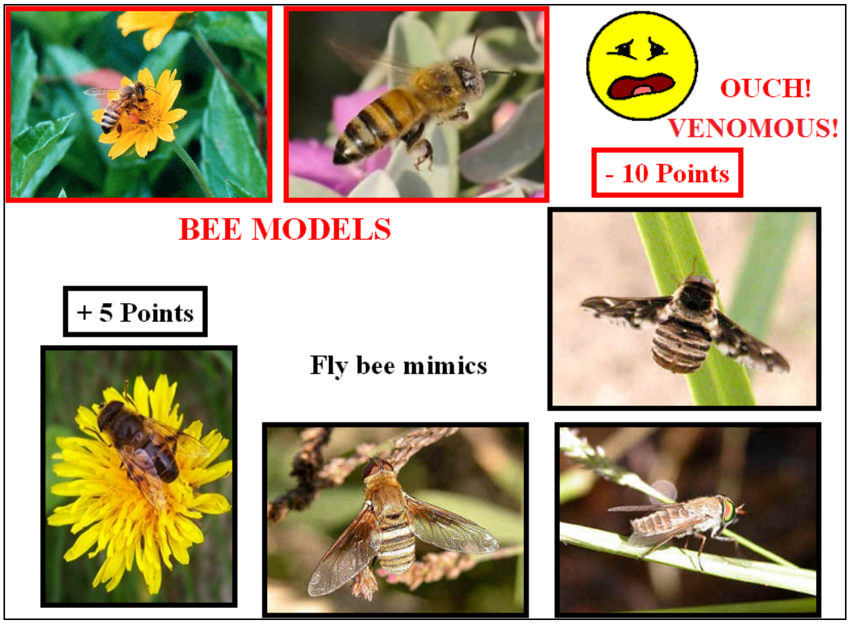
Key to models and mimics & distinguishing characters of insect orders.

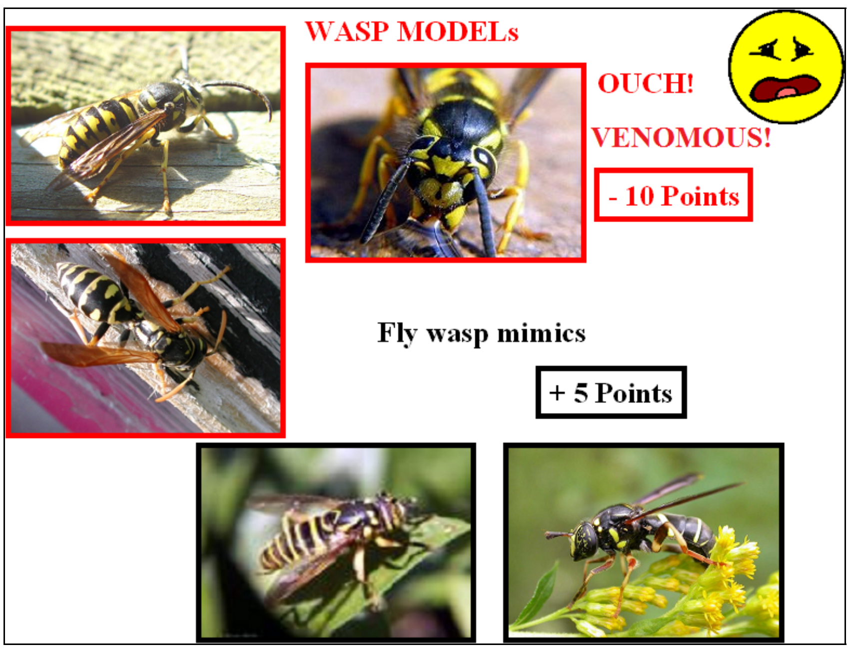


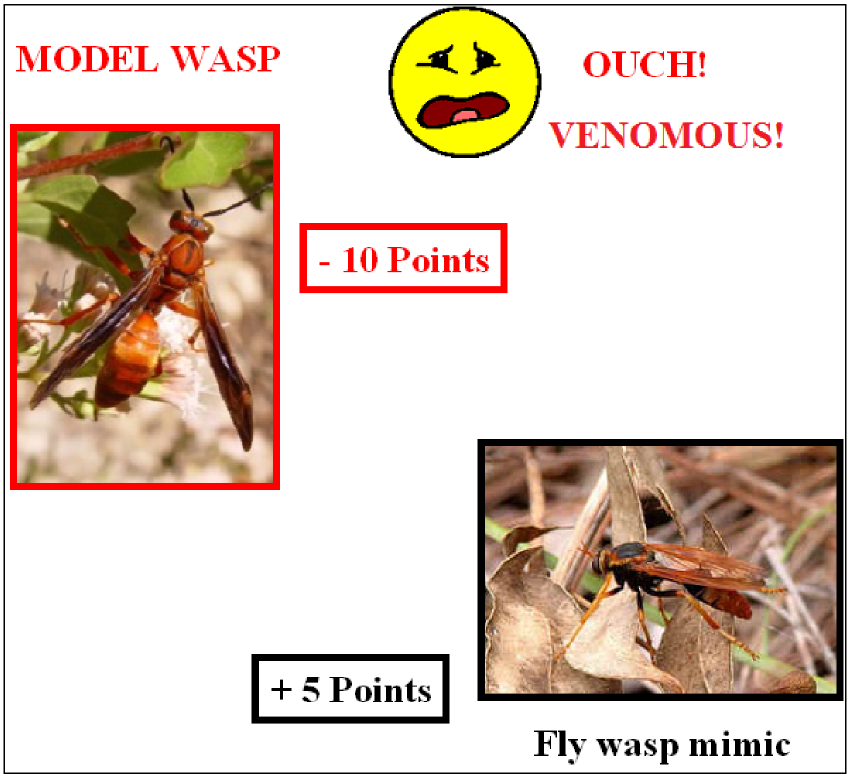


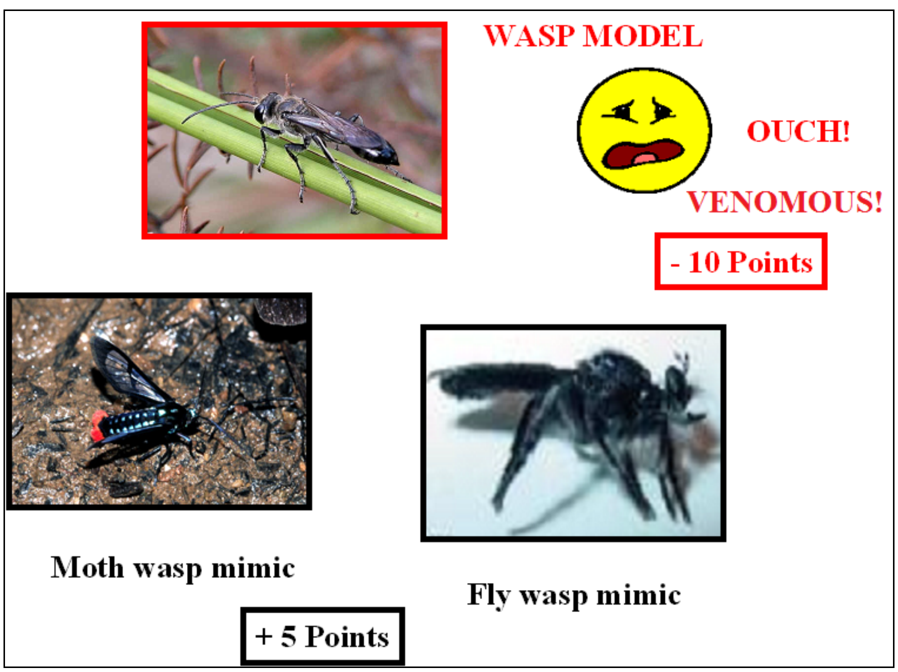

VELVET ANT (MUTILID WASP) MODEL
OUCH!
VENOMOUS!
- 10 Points
Beetle mimic
+ 5 Points

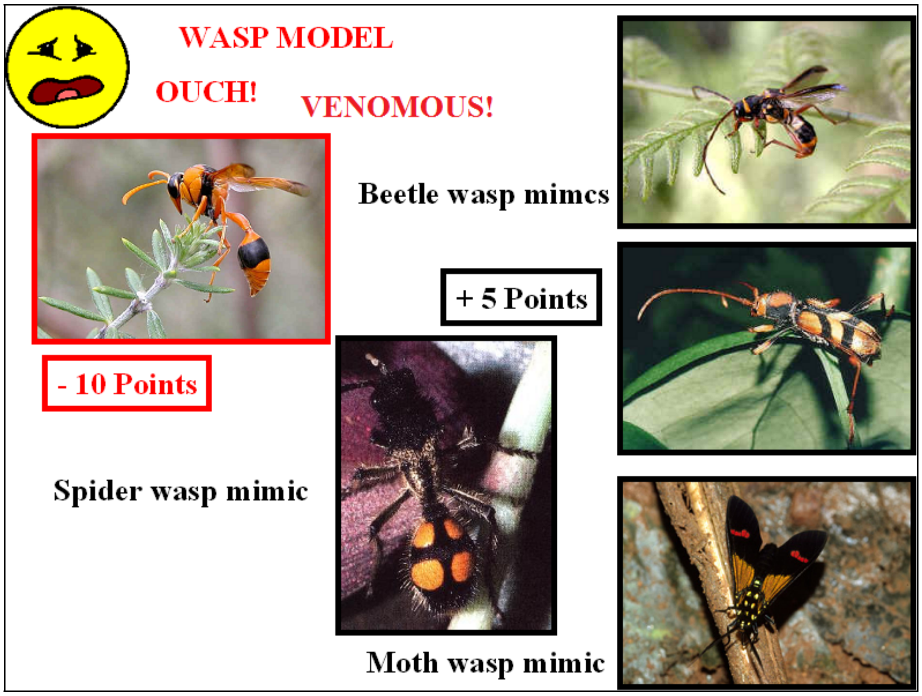

LYCID BEETLE MODELS
YUCK!
POISONOUS/
TASTES BAD
- 10 Points
Moth mimics
Beetle mimics
+ 5 Points

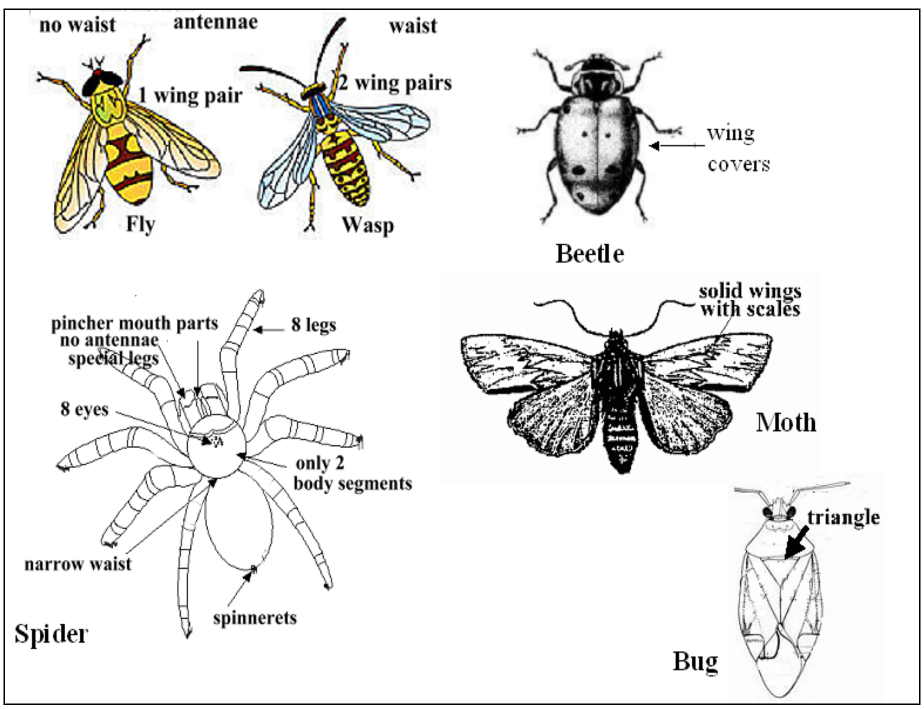

OUCH!
VENOMOUS!
- 10 Points
BEE MODELS
+ 5 Points
Fly bee mimics

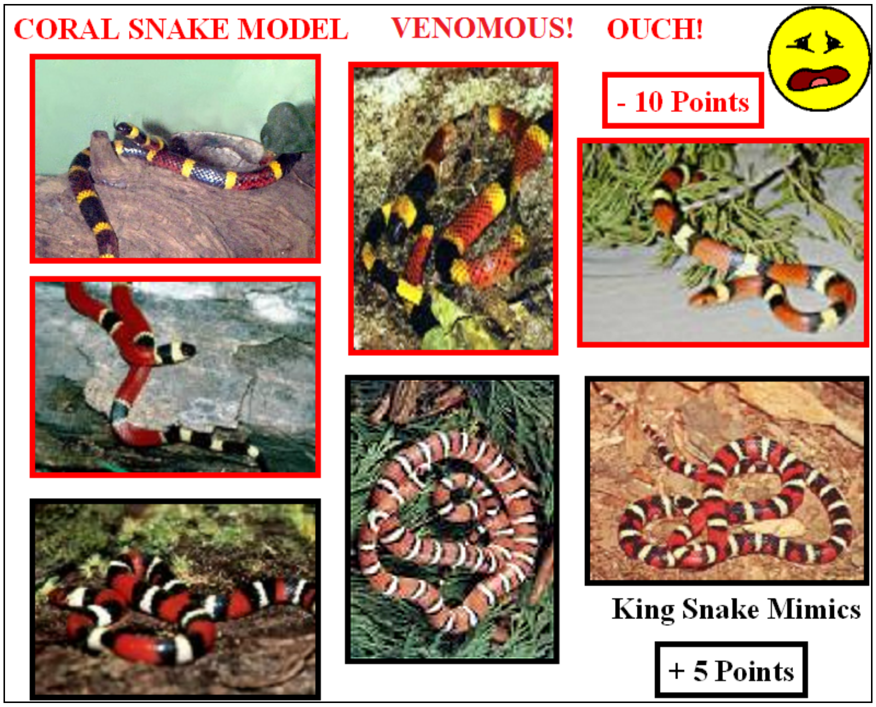

WASP MODELs
OUCH!
VENOMOUS!
- 10 Points
Fly wasp mimics
+ 5 Points

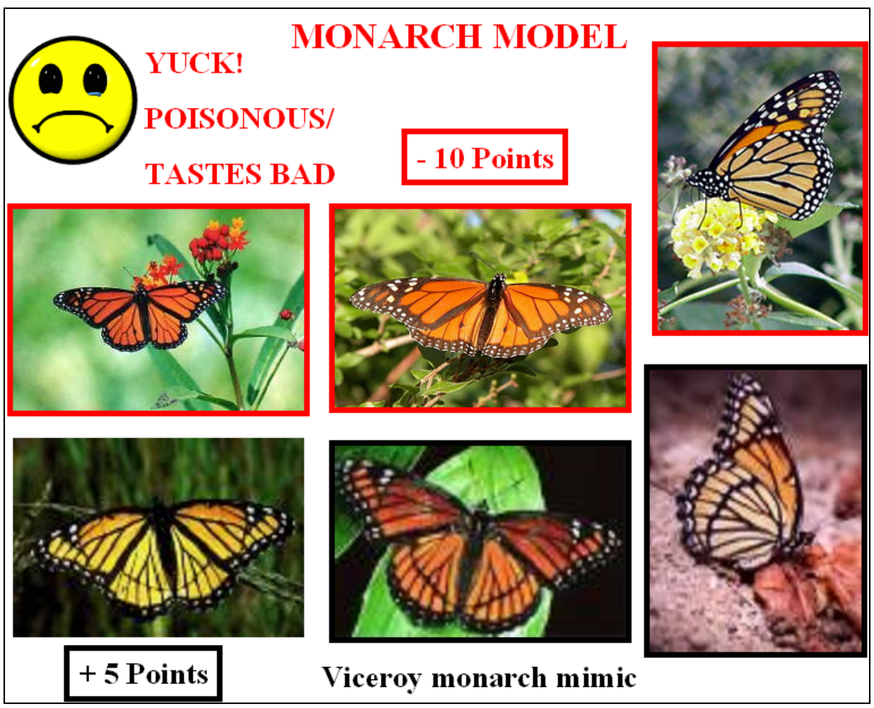

MODEL WASP
OUCH!
VENOMOUS!
- 10 Points
+ 5 Points
Fly wasp mimic


WASP MODEL
OUCH!
VENOMOUS!
- 10 Points
Moth wasp mimic
Fly wasp mimic
+ 5 Points


WASP MODEL
OUCH!
VENOMOUS!
Beetle wasp mimcs
+ 5 Points
- 10 Points
Spider wasp mimic
Moth wasp mimic


no waist
antennae
waist
1 wing pair
2 wing pairs
Fly
Wasp
wing
covers
Beetle
pincher mouth parts
no antennae
special legs
8 legs
8 eyes
only 2
body segments
narrow waist
spinnerets
Spider
solid wings
with scales
Moth
triangle
Bug


CORAL SNAKE MODEL
VENOMOUS!
OUCH!
- 10 Points
King Snake Mimics
+ 5 Points


MONARCH MODEL
YUCK!
POISONOUS/
TASTES BAD
- 10 Points
+ 5 Points
Viceroy monarch mimic

Answers for Questions in Exercise 3.2b: Slap Snack Mimic

Q1. If you selected a card at random from Mimic Deck 1, what is the probability that the card is a mimic card?

$$\boldsymbol{Probability(mimic) = \frac{\#\ of\ mimic\ cards}{total\ \#\ of\ cards} = \frac{4}{25} = 0.16 = 16\%}$$

Q2. If you selected a card at random from Mimic Deck 1, what is the probability that the card is a model (poisonous or venomous) card?

$$\boldsymbol{Probability(model) = \frac{\#\ of\ model\ cards}{total\ \#\ of\ cards} = \frac{6}{25} = 0.24 = 24\%}$$

Q3. If you selected a card at random from Mimic Deck 1, what is the probability that the card is a nutritious non-mimic card?

$$\boldsymbol{Probability(nonmimic) = \frac{\#\ of\ nonmimic\ cards}{total\ \#\ of\ cards} = \frac{15}{25} = 0.60 = 60\%}$$

Q4. Using the card values and the probabilities you calculated in Q1-Q3, what is the *expected value* for one card drawn from Mimic Deck 1?

$$\boldsymbol{Expected\ Value = 2(0.60) + 5(0.16) - 10(0.24) = 1.20 + 0.80 - 2.4 = -0.4}$$

Q5. If you selected a card at random from Mimic Deck 2, what is the probability that the card is a mimic card?

$$\boldsymbol{Probability(mimic) = \frac{\#\ of\ mimic\ cards}{total\ \#\ of\ cards} = \frac{7}{25} = 0.28 = 28\%}$$

Q6. If you selected a card at random from Mimic Deck 2, what is the probability that the card is a model (poisonous or venomous) card?

$$\boldsymbol{Probability(model) = \frac{\#\ of\ model\ cards}{total\ \#\ of\ cards} = \frac{3}{25} = 0.12 = 12\%}$$

Q7. If you selected a card at random from Mimic Deck 2, what is the probability that the card is a nutritious non-mimic card?

$$\boldsymbol{Probability(nonmimic) = \frac{\#\ of\ nonmimic\ cards}{total\ \#\ of\ cards} = \frac{15}{25} = 0.60 = 60\%}$$

Q8. Using the card values and the probabilities you calculated in Q5-Q7, what is the *expected value* for one card drawn from Mimic Deck 2?

$$\boldsymbol{Expected\ Value = 2(0.60) + 5(0.28) - 10(0.12) = 1.20 + 1.40 - 1.20 = 1.40}$$

Q9. Compare your answers from Mimic Decks 1 and 2. In what ways are Decks 1 and 2 quantitatively different? Which deck is "easier" on predators? Therefore, under what conditions does mimicry work best for prey? Does this make sense? Justify your answer.

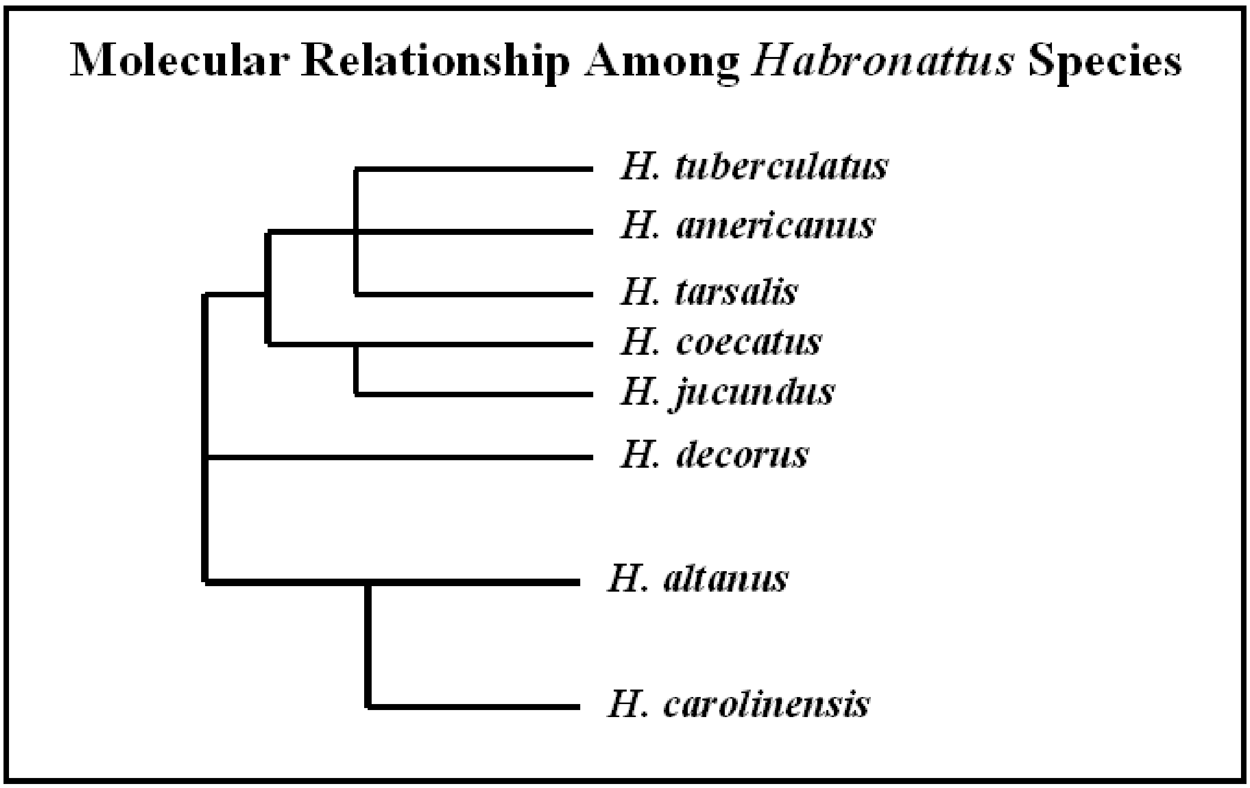
In both decks, the relative frequencies of nutritious, non-mimic prey items are the same. However, in Deck 1, the relative frequency of chemically defended (venomous or poisonous) model prey items is higher than that in Deck 2, and the relative frequency of aposematic (yet harmless and nutritious) mimic prey items is lower than that of Deck 2.

In Deck 1, model organisms occur more frequently than mimics, and in Deck 2, mimics occur more frequently than models. Also, when comparing the expected values of each deck, you should see that the expected value of a card in Deck 2 is higher than the expected value of a card in Deck 1. In fact, the expected value of a card in Deck 2 is a positive value, while the expected value of a card in Deck 1 is negative. In other words, a predator in the environment simulated by Deck 2 has a greater potential payoff to just attack/eat any potential prey item at random, since it has a greater chance of encountering a tasteful mimic than a toxic/dangerous model, and can usually get away with taking prey even if they exhibit warning coloration.

In the environment simulated by Deck 1, predators are actually more likely to be injured or get sick (or worse!) if they attack/eat any potential prey item at random. This should illustrate that mimicry usually works best for prey when dangerous model organisms are more abundant than the mimics themselves.

Answers for Exercise 3.3b: Comparing Ethograms

Below is a phylogeny (a branching tree showing evolutionary relationships) of the eight species of *Habronattus* from Exercise 3, based on molecular (DNA) evidence. Did your branching diagram based on male courtship behavior show similar relationships?



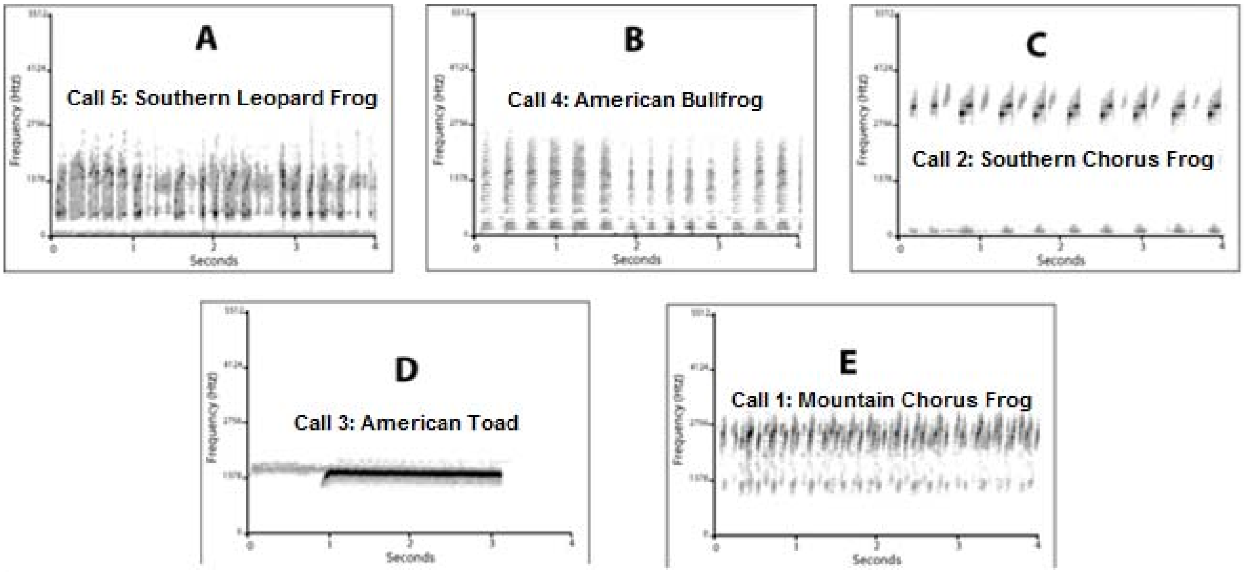
ANSWERS FOR EXERCISE 4

Answers for Exercise 4.3: What Kind of Frog?

1. True Frog - Pig Frog (*Rana grylio*)
2. Toad - Southern Toad (*Bufo terrestris*)
3. Tree Frog - Upland Chorus Frog (*Pseudacris feriarum*)
4. Tree Frog - Southern Chorus Frog (*Pseudacris nigrita*)
5. True Frog - Southern Leopard Frog (*Rana sphenocephala*)
6. Toad - Fowler's Toad (*Bufo fowleri*)
7. True Frog - American Bullfrog (*Rana catesbiana*)
8, Tree Frog - Brimley's Chorus Frog (*Pseudacris brimleyi*)
9. Toad - American Toad (*Bufo americanus*)
10. True Frog - Pickerel Frog (*Rana palustris*)
11. Tree Frog - Mountain Chorus Frog (*Pseudacris brachyphona*)

You can see pictures of each of these frogs on page 66.

Answers for Exercise 4.4: Frog Calls on Paper: Reading Spectrograms



ANSWERS FOR EXERCISE 6

Q1. If you are testing your subject(s) for preference between two options, should you place the two options between which they will choose on the same arm of the maze each time? Why or why not?

You should not place the options in the same arms of the maze each time. This is because the subjects may exhibit "handedness," and may simply prefer to turn left or right in the maze, and may not reflect their actual preferences (if any exist) between the two choices of items, scents, etc. that they are offered. As mentioned in the introduction to the exercise, the test subject may also exhibit a tendency to go to alternating arms on successive trials. Due to each of these factors, on each trial, the arm in which each option is place should ideally be randomized.

Q2. State the null and alternative statistical hypotheses that the researcher would address when analyzing these data.

H_0: The local population of the butterfly species in question does NOT exhibit a population level preference of flower color.

H_A: The local population of the butterfly species in question DOES exhibit a population level preference of flower color.

Q3. Construct a table that allows you to calculate the value of χ^2 for this experiment.

Category	Observed Frequency (O)	Expected Frequency (E)	(O - E)	$(O - E)^2$	$(O - E)^2/E$
Pink	202	180	22	484	2.6889
White	151	180	-29	841	4.6722
Red	193	180	13	169	0.9389
Blue	174	180	-6	36	0.2000
TOTAL	720	720	0	1530	$\chi^2 = 8.50$

Q4. For the researcher's study, the critical value for χ^2 (based on 3 degrees of freedom) is equal to 7.51. Based on your calculation of χ^2 in the previous question, would the researcher reject or fail to reject the null hypothesis? What does this mean?

The calculated value of χ^2 (8.50) is greater than the critical value of χ^2 (7.51) for this test. Because of this, the researcher should reject the null hypothesis, and conclude, based on the data from this study, that the local population of the butterfly species in question DOES exhibit differential preferences for the presented flower colors.

ANSWERS FOR EXERCISE 7

Q1. Calculate the absolute fitness for each of the two following traits A and B.

Trait A: Individuals possessing trait A have a probability of surviving to reproduction of 2/3, and survivors contribute 5 viable offspring to the next generation.

Trait B: Individuals possessing trait B have a probability of surviving to reproduction of ½ and surviving individuals contribute 4 viable offspring to the next generation

Remember, absolute fitness is estimated as the product of the survival of individuals possessing a particular trait and average number of offspring contributed by individuals possessing the trait to the next generation. Thus, the absolute fitness of each trait would be calculated as follows:

$$\boldsymbol{For\ Trait\ A}: \boldsymbol{w_{abs}} = \frac{\mathbf{2}}{\mathbf{3}} \times \mathbf{5} = \frac{\mathbf{10}}{\mathbf{3}} \approx \mathbf{3.33}$$

$$\boldsymbol{For\ Trait\ B}: \boldsymbol{w_{abs}} = \frac{\mathbf{1}}{\mathbf{2}} \times \mathbf{4} = \frac{\mathbf{4}}{\mathbf{2}} = \mathbf{2}$$

Q2. Based on your calculation of absolute fitness of Trait A and Trait B in Q1, what is the relative fitness of each of these traits? Calculate these values using both methods Estimate 1 & Estimate 2 as described above.

$$\boldsymbol{Relative\ Fitness\ (Estimate\ 1)} = \frac{\boldsymbol{Average\ N\ of\ Trait\ 1\ after\ selection}}{\boldsymbol{Average\ N\ of\ Trait\ 2\ after\ selection}} = \frac{\mathbf{3.33}}{\mathbf{2}} \approx \mathbf{1.67}$$

$$\boldsymbol{Relative\ Fitness\ (Estimate\ 2)} = \frac{\boldsymbol{Average\ N\ of\ Trait\ X\ after\ selection}}{\boldsymbol{Greatest\ N\ after\ selection\ (of\ all\ traits)}} = \frac{\mathbf{2}}{\mathbf{3.33}} \approx \mathbf{0.6}$$

Both of these estimates express the same thing: Trait B is relatively less fit than Trait A.

Q3. What are the relative frequencies of the three colors at the end of the experiment? How many generations of selection were completed? Which color was preferred by the predators (students) in the experiment? Which color had the greatest fitness?

The relative frequency of black jellybeans at the end of the experiment was 0.8 or 80%, the relative frequency of green was 0.1 or 10%, and the relative frequency of orange was 0.1 or 10%. Three generations of selection (predation) were completed. The green and orange jellybeans were equally highly preferred, making the black jellybeans the most fit, as the largest number survived to reproduce.

Q4. If populations are at adaptive equilibrium, why does natural selection continue to operate in most contexts?

Stabilizing selection occurs each generation as genetic mixing during sexual reproduction produces traits in offspring that may not be adaptive.

Q5. Examine the trait distributions before and after selection shown in Figure 4. Try to come up with a consensus as to what type of selection (directional,

disruptive/diversifying, or stabilizing) is operating for the graphs in Figures 4A, 4B, and 4C.

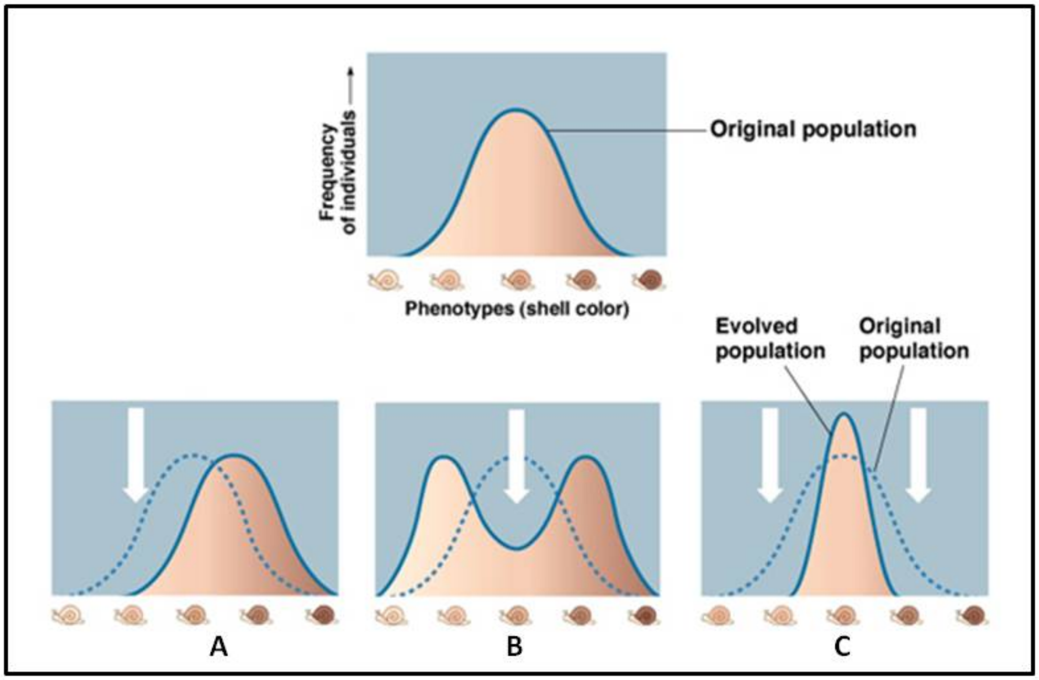


Figure 4A shows directional selection, with the mean (average) phenotype shifting to the right (the average coloration of individuals in the population becomes darker). Figure 4B illustrates disruptive/diversifying selection, in which the original mean phenotype becomes selected against, with individuals at either extreme being favored, eventually resulting in a bimodal distribution of the phenotype (with lighter individuals and darker individuals becoming more common). Finally, Figure 4C illustrates stabilizing selection, in which the mean value of the phenotype does not change, but the variation in the phenotype decreases (due to strong selection against individuals varying substantially from the original population mean).

Q6. What potential general evolutionary patterns might you observe in the squirrel caching experiment you are about to complete? By evolution here, we are referring to changes in the frequencies of genes underlying the different caching strategies.

Essentially, relative frequencies of a given caching tactic could increase, decrease, or stay the same.

Q7. Suppose that the entire squirrel population with a carrying capacity of 28 recovers 26 acorn chips. What is the probability that one of these offspring survives to the next year? What is the probability that a squirrel survives if the population recovers 100 acorns?

In the first scenario where 26 acorn chips were recovered, the probability that a single offspring survives to the following year would be equal to 1 (100%), since a number of offspring less than the carrying capacity would be born (26 < 28). In the second scenario, if 100 chips were recovered, that would mean 100 offspring were born. Since this is larger than the carrying capacity, the probability that an offspring would survive is equal to 28/100 = 0.28 = 28%.

Q8. What happens to the probability that a squirrel survives to the next year as the number of offspring born increases?

As the number of offspring born increases, the probability of survival to the next year decreases (as long as the total number of offspring born is greater than the carrying capacity).

SUGGESTED READING

Grades K-3

The Five Senses (General & Miscellaneous)
My Five Senses - Aliki
The Magic School Bus Explores the Senses - Joanna Cole & Bruce Degen (Illustrator)
The Five Senses - Sally Hewitt
Animal Senses: How Animals See, Hear, Taste, Smell and Feel - Pamela Hickman & Pat Stephens (Illustrator)
Look, Listen, Taste, Touch, and Smell: Learning about Your Five Senses - Pamela Hill Nettleton & Becky Shipe (Illustrator)
You Can't Taste a Pickle With Your Ear - Harriet Ziefert & Amanda Haley (Illustrator)
Sense-Abilities: Fun Ways to Explore the Senses - Michelle O'Brien-Palmer

The Sense of Touch
The Sense of Touch - Elaine Landau
Touch - Maria Rius, J.M. Parramon, & J.J. Puig

The Sense of Smell
My Nose - Lloyd G. Douglas
Smelling - Sharon Gordon
Smell - Maria Rius, J.M. Parramon, & J.J. Puig
The Sense of Smell - Ellen Weiss

The Sense of Vision
How Animals See Things - Allan Fowler
Seeing Things - Allan Fowler
Young Genius: Eyes - Kate Lennard & Eivind Gulliksen (Illustrator)
The Eye Book by Dr. Seuss - Theo LeSieg & Joe Mathieu (Illustrator)
Sight - Maria Rius, J.M. Parramon, & J.J. Puig

The Sense of Hearing
Hearing - Helen Frost
Animal Hearing - Kirsten Hall
Can You Hear a Rainbow?: The Story of a Deaf Boy Named Chris - Jamee Riggio Heelan & Nicola Simmonds (Illustrator)
The Sense of Hearing - Elaine Landau
Shhhh...: A Book About Hearing - Dana Meachen Rau & Rick Peterson (Illustrator)
Hearing - Maria Rius, J.M. Parramon, & J.J. Puig

The Sense of Taste
Taste - Maria Rius, J.M. Parramon, & J.J. Puig
The Sense of Taste - Ellen Weiss

Grades 4-6

The Five Senses (General & Miscellaneous)
How to Really Fool Yourself: Illusions for All Your Senses - Vicki Cobb
Animal Talk: How Animals Communicate through Sight, Sound and Smell - Etta Kaner & Greg Douglas (Illustrator)
Understanding Your Senses - Rebecca Treays
You've Got Nerve!: The Secrets of the Brain and Nerves - Melissa Stewart & Janet Hamlin (Illustrator)

The Sense of Smell
Up Your Nose!: The Secrets of Schnozes and Snouts - Melissa Stewart & Janet Hamlin (Illustrator)

The Sense of Vision
Seeing Color: It's My Rainbow, Too - Arlene Evans
The Optics Book: Fun Experiments with Light, Vision & Color - Shar Levine & Leslie Johnstone
Just Like Grandpa: A Story About Color Vision Deficiency - Elizabeth Murphy-Melas & Mary Kate Wright (Illustrator)
Eyes and Ears - Seymour Simon
The Eyes Have It: The Secrets of Eyes and Seeing - Melissa Stewart & Janet Hamlin (Illustrator)

The Sense of Hearing
Now Hear This!: The Secrets of Ears and Hearing - Melissa Stewart & Janet Hamlin (Illustrator)
How Do Bats Fly in the Dark? - Melissa Stewart
Eyes and Ears - Seymour Simon

Grades 7+

The Human Brain Book - Rita Carter
The Senses - Douglas B. Light
Hearing Disorders - Henry Wouk

Scientific Journal Articles (included on Teacher CD)

The Tactile Sense

Catania, K.C. 1999. A nose that looks like a hand and acts like an eye: the unusual mechanosensory system of the star-nosed mole. *Journal of Comparative Physiology A* 185:367-372.

Okada, J. & S. Akamine. 2012. Behavioral response to antennal tactile stimulation in the field cricket *Gryllus bimaculatus*. *Journal of Comparative Physiology A* 198:557-565.

Patullo, B.W. & D.L. Macmillan. 2006. Corners and bubble wrap: the structure and texture of surfaces influence crayfish exploratory behaviour. *The Journal of Experimental Biology* 209:567-575.

Chemical Olfaction

Hoover, K.C. 2010. Smell With Inspiration: The Evolutionary Significance of Olfaction. *Yearbook of Physical Anthropology* 53:63-74.

Siniscalchi, M., R. Sasso, A.M. Pepe, S. Dimatteo, G. Vallortigara, & A. Quaranta. 2011. Sniffing with the right nostril: lateralization of response to odour stimuli by dogs. *Animal Behaviour* 82:399-404.

Williams, M. & J.M. Johnston. 2002. Training and maintaining the performance of dogs (*Canis familiaris*) on an increasing number of odor discriminations in a controlled setting. *Applied Animal Behaviour Science* 78:55-65.

Vision

Brower, J. 1960. Experimental Studies of Mimicry. IV. The Reactions of Starlings to Different Proportions of Models and Mimics. *The American Naturalist* 94(877):271-282.

Clark, D.L. & G.W. Uetz. 1993. Signal efficacy and the evolution of male dimorphism in the jumping spider, *Maevia inclemens*. *Proceedings of the National Academy of Sciences of the United States of America* 90:11954-11957.

Kevan, P. M. Giurfa, & L. Chittka. 1996. Why are there so many and so few white flowers? *Trends in Plant Science* 1(8):280-284.

Kevan, P.G., L. Chittka, & A.G. Dyer. 2001. Limits to the salience of ultraviolet: Lessons from colour vision in bees and birds. *The Journal of Experimental Biology* 204:2571-2580.

Rowe, C. & J. Skelhorn. 2005. Colour biases are a question of taste. *Animal Behaviour* 69:587-594.

Skelhorn, J. & C. Rowe. 2006. Avian predators taste-reject aposematic prey on the basis of their chemical defence. *Biology Letters* 2:348-350

Svadova, K., A. Exernova, P. Stys, E. Landova, J. Valenta, A. Fucikova, & R. Socha. 2009. Role of different colours of aposematic insects in learning, memory and generalization of naive bird predators. *Animal Behaviour* 77: 327-336.

Hearing

Masters, W.M. & H. Markl. 1981. Vibration Signal Transmission in Spider Orb Webs. *Science, New Series* 213(4505):363-365.

Schnitzler, H. & E.K.V. Kalko. 2001. Echolocation by Insect-Eating Bats. *BioScience* 51(7):557-569.
Schnitzler, H., C.F. Moss, & A. Denzinger. 2003. From spatial orientation to food acquisition in echolocating bats. *Trends in Ecology & Evolution* 18(8):386-394.
Siemers, B.M. & H. Schnitzler. 2004. Echolocation signals reflect niche differentiation in five sympatric congeneric bat species. *Nature* 429:657-661.

Temperature Effects
Esteban, M., M.J. Sanchez-Herraiz, L.J. Barbadillo, J. Castanet, & R. Marquez. 2002. Effects of age, size and temperature on the advertisement calls of two Spanish populations of *Pelodytes punctatus*. Amphibia-Reptilia 23:249-258.
Hill, P.S.M. 1998. Environmental and social influences on calling effort in the prairie mole cricket (*Gryllotalpa major*). *Behavioral Ecology* 9(1):101-108.
Navas, C.A. & C.R. Bevier. 2001. Thermal Dependency of Calling Performance in the Eurythermic Frog *Colostethus subpunctatus*. *Herpetologica* 57(3):384-395.
Navas, C.A. 1996. Thermal Dependency of Field Locomotor and Vocal Performance of High-Elevation Anurans in the Tropical Andes. *Journal of Herpetology* 30(4):478-487.
Pires, A. & R.R. Hoy. 1992. Temperature coupling in cricket acoustic communication. I. Field and laboratory studies of temperature effects on calling song production and recognition in *Gryllus firmus*. *Journal of Comparative Physiology A* 171:69-78.
Wong, B.B.M., A.N.N. Cowling, R.B. Cunningham, C.F. Donnelly, & P.D. Cooper. 2004. Do temperature and social environment interact to affect call rate in frogs (*Crinia signifera*)? *Austral Ecology* 29:209-214.

T-Mazes
Evans, T.A., R. Inta, J.C.S. Lai, & M. Lenz. 2007. Foraging vibration signals attract foragers and identify food size in the drywood termite, *Cryptotermes secundus*. *Insectes Sociaux* 54:374-382.
Jakob, E.M., C.D. Skow, M.P. Haberman, & A. Plourde. 2007. Jumping Spiders Associate Food With Color Cues In a T-Maze. *Journal of Arachnology* 35(3):487-492.
Rodriguez, M., C. Gomez, J. Alonso, & D. Afonso. 1992. Laterality, Alteration, and Perseveration Relationships on the T-Maze Test. *Behavioral Neuroscience* 106(6):974-980.

Caching
Penner, J.L. & L.D. Devenport. 2011. A Comparative Study of Caching and Pilfering Behavior in Two Sympatric Species, Least Chipmunks (*Tamias minimus*) and Eastern Chipmunks (*Tamias striatus*). *Journal of Comparative Psychology* 125(4):375-384.
Vander Wall, S.B., M.S. Enders, & B.A. Waitman. 2009. Asymmetrical cache pilfering between yellow pine chipmunks and golden-mantled ground squirrels. *Animal Behaviour* 78:555-561.
Wang, B., G. Wang, & J. Chen. 2012. Scatter-hoarding rodents use different foraging strategies for seeds from different plant species. *Plant Ecology* 213:1329-1336.

LINKS

Read With Your Fingers - information from OLogy on Braille (how the blind can read) using their tactile sense. Includes an activity on creating your own Braille messages.
http://www.amnh.org/ology/features/readwithfingers/

Taste a Smell Test - another activity from OLogy that demonstrates how the senses of smell and taste interact.
http://www.amnh.org/ology/features/jellybeantest/

Trip Up Your Brain - a few interesting activities from OLogy (from the American Museum of Natural History) that demonstrate how our senses can interact to "fool" our brains.
http://www.amnh.org/ology/features/tripupyourbrain/

Five Senses Teaching Theme Ideas - several activities on the five senses for kindergarteners
http://www.littlegiraffes.com/fivesenses.html

21 Five Senses Activities for Kids - Pretty self-explanatorily titled link with lots of activities on the senses.
http://www.notimeforflashcards.com/2012/10/21-five-senses-activities-for-kids.html

Neuroscience for Kids - Great website from Dr. Eric Chudler from the University of Washington; has lots of activities, as well as background information on how the senses work.
http://faculty.washington.edu/chudler/neurok.html

Human Body: Five Senses - eThemes - collection of lesson plans and links compiled by the University of Missouri
http://ethemes.missouri.edu/themes/624

It's All in Your Mind - website from the University of Texas Health Science Center in San Antonio with lots of information and activities on brain anatomy and health
http://teachhealthk-12.uthscsa.edu/curriculum/brain/brain.asp

Kids DO Science: Behavior & Adaptations - lesson plan and activities exploring animal behavior from The University of Georgia's Savannah River Ecology Laboratory
http://srel.uga.edu/kidsdoscience/kidsdoscience-behavior.htm

Ethogram & Animal Behavior Research - a 124 page book with activities and info for kids in grades 5-8; developed by teachers with educators at the St. Louis Zoo
http://schoolpartnership.wustl.edu/wp-content/uploads/2013/01/AnimalBehavior.pdf

Physics of Animal Behavior - website with activities for all grade levels K-12 from the Cornell University Laboratory of Ornithology
http://www.birds.cornell.edu/physics/lessons/home

Squirrelly Behavior - website from the Smithsonian National Zoological Park with lesson plan, information, and activities for students to conduct a study of squirrel behavior
http://nationalzoo.si.edu/Education/ClassroomScience/Behavior/Teacher/default.cfm