Unit 6: Animal Kingdom

Biology in a Box

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This unit revised October 2012

Unit 6: Animal Kingdom
Materials List

- Game spinner
- Magnifying glass
- Phylogenetic tree poster
- 23 organism specimens, consisting of representatives of the nine major animal phyla
- Mystery animal
- Straw
- Larger diameter tubing
- Bags (6) of assorted shells (10 shells/bag) labeled "*Exercise 9a/9b*"
- Sealed Petri dishes containing half of a nautilus shell, with gridlines drawn on the lids (6)
- Rulers (6)
- Protractors (6)
- Package of rubber bands

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Introduction

You are familiar with many different living things. The Earth's organisms are so diverse that it is an overwhelming task to classify them. Nonetheless, scientists attempt to assign organisms into groups called **kingdoms** based on their structure, development, feeding patterns, and more recently, their genes. There are six kingdoms in all: **Bacteria, Archaea, Protista, Fungi, Plantae,** and **Animalia**.

The **Kingdoms Bacteria** and **Archaea** both contain single-celled organisms that have no membrane-bound organelles. As a result, these organisms have no special compartments where various cell functions are carried out. In particular, their genetic material floats freely in the cell. Although the Kingdoms Bacteria and Archaea have similar structural characteristics (formerly, they were grouped together into the Kingdom Monera), genetically they are distinct, and so they are now classified into separate kingdoms.

The **Kingdom Protista** also includes single-celled organisms, but the protist cell has compartments in it. Each compartment, consisting of a membrane-bound organelle, serves some specialized function. For instance, genetic material is located in an organelle called the nucleus.

Like organisms in the Kingdom Protista, organisms in the next three kingdoms have compartmentalized cells. These organisms, however, are composed of many cells, and are much larger and more complex. The **Kingdom Fungi** contains organisms (for example mushrooms and molds) that decompose organic matter, such as fallen leaves, animal carcasses, and feces, into simpler chemical compounds. Decomposers absorb nutrients from the material they decompose. The **Kingdom Plantae** contains organisms (for example trees and mosses) that make their own food using the energy from sunlight. Finally, the **Kingdom Animalia** contains most of the multi-celled organisms (like insects, fish, and mammals) that consume other living organisms for food. (There are a few plants and fungi that will consume other living organisms, though this is not their primary source of nourishment.)

In the following exercises, students will gain a broad overview of the biodiversity present here on earth, particularly focusing on the Animal Kingdom. Each exercise presents information that builds on the previous exercise, so it may be beneficial to do these exercises in sequential order. However, teachers may use their own discretion as to which exercises to present to their students based on grade level and topics already covered in the classroom.

- In **Exercise 1: Graph that Diversity**, students explore the diversity present in each of the six kingdoms of life, using two different types of graphs.
- In **Exercise 2: Animal Symmetry**, students will learn about the different types of patterns of self-similarity, or symmetry, present in animals.
- **Exercise 3: Guess that Phylum** presents students of all grade levels with an interactive matching game that helps them learn how to distinguish the nine major animal phyla, using actual specimens.
- In **Exercise 4: Diagram those Traits**, students explore differences and similarities among the nine major animal phyla by learning how to interpret and construct Venn diagrams.
- **Exercise 5: Sort these Animals** provides a framework in which younger students (grades K-2) can explore the similarities and differences among the major animal phyla. Two different approaches introduce the concepts of classification and the inter-relatedness of animals. An open-ended exploration of the topics is also presented.
- In **Exercise 6: Who's in that Tree?**, students are introduced to the concept of phylogenies, or evolutionary relationships between groups of organisms.
- **Exercise 7: What is that Animal?** presents students with a mystery organism, which they will try to assign to one of the major animal phyla about which they have learned from previous exercises.
- **Exercise 8: Pass that Gas!**, students explore surface area to volume ratios, and discover the biological basis of size constraints in modern insects.

- Finally, **Exercise 9: Follow that Spiral!** presents students with an example of a natural phenomenon (mollusc shell shape) that can be modeled by a mathematical function. This exercise incorporates various measurements of shells, a puzzle using congruent shapes to model nautilus shell growth, as well as a challenge to estimate the equation of an actual nautilus shell.

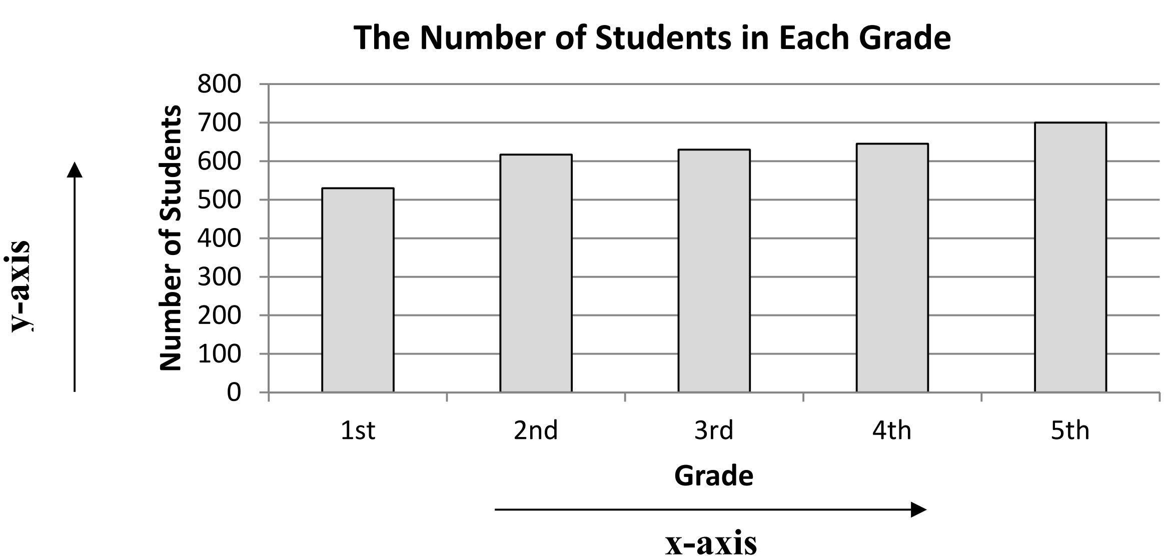
Exercise 1: Graph that Abundance

With new molecular fingerprinting techniques, it has become clear that the **Kingdom Bacteria*** has by far the greatest number of different kinds of organisms. However, taxonomists have barely started to sort out this diversity with the described bacteria species numbering at a mere 10,000, compared to 1,400,000 species known for the **Kingdom Animalia,** 320,000 for the **Kingdom Plantae, 100,000 for each of the Kingdoms Fungi** and **Protista** and a mere 259 species for the **Kingdom Archaea***.

***Although very few Bacteria and Archaea have been identified, this does not mean that there are not a lot of them, instead it reflects the fact that they are difficult to observe. Most of these organisms can only be seen through a microscope, and the differences between them are often genetic, and therefore more difficult to detect. Only recently, with the aid of new molecular technologies, have scientists begun to study these organisms more closely. Recent estimates based on mathematical models place the actual number of species in the Kingdom Bacteria to be in the tens of millions.**

- On a sheet of paper, make a bar graph that displays the number of known organisms (species) in each of the six kingdoms. Figure 1 is an example of a bar graph. Your teacher may supply you with a template (found on page 11) to assist you with this task. There are also directions on making a bar graph on the following page, which may also be useful to you.

Figure 1. This bar graph displays the number of students in each grade from 1st to 5th. The grade that each bar represents is recorded along the horizontal, or x-axis. The height of a bar, as measured along the vertical, or y-axis, tells us the number of students in the corresponding grade.



Instructions for making a bar graph:

You are going to construct a **bar graph** using the data on page 4 telling you the known numbers of species in each Kingdom. Figure 1 on page 4 is an example of a bar graph that you can use as a guide when you construct your bar graph. Each bar in the sample graph represents a different grade level, and the height of each bar indicates the number of students in each grade at a particular school.

Similar to the example graph, your graph will show a different bar for each of the Kingdoms used to classify living organisms, and the height of each bar will represent the number of species in each of the Kingdoms. If each bar in your graph will represent one Kingdom, how many bars will your graph have in all? If you said 6, you are exactly right!

- Look at the numbers of species in the six Kingdoms (on the previous page).

These numbers are quite a bit larger than the numbers in the sample graph, so you are going to need to find a way to represent all the numbers so that your graph will fit on your paper. The y-axis, or vertical axis, will show the numbers of species in each Kingdom using a scale that you choose.

- Remember that the scale you use for indicating numbers of species must be divided into even increments as you move up the vertical (side) axis!
    - In order to help you with this, consider the following questions:
    - What is the smallest number of species in any one Kingdom?
    - What is the largest number of species in any one Kingdom?
    - What is the difference in the largest and smallest number of species?
    - How many spaces do you have to work with on your graph paper?

You will use that information to help you design your graph. Because of the large difference between the largest and smallest numbers of species, and also because of having limited space on your paper, the scale intervals will need to represent a large number. In other words, you may want each space to represent 40,000 or 50,000 so that all Kingdoms' numbers will be represented on your graph.

- Whichever number you choose as your interval, be sure to begin at 0 (zero) and end at a number that will include the largest number in your data.
- Also, be sure that each interval is equally spaced and represents the same difference as you move up the graph.

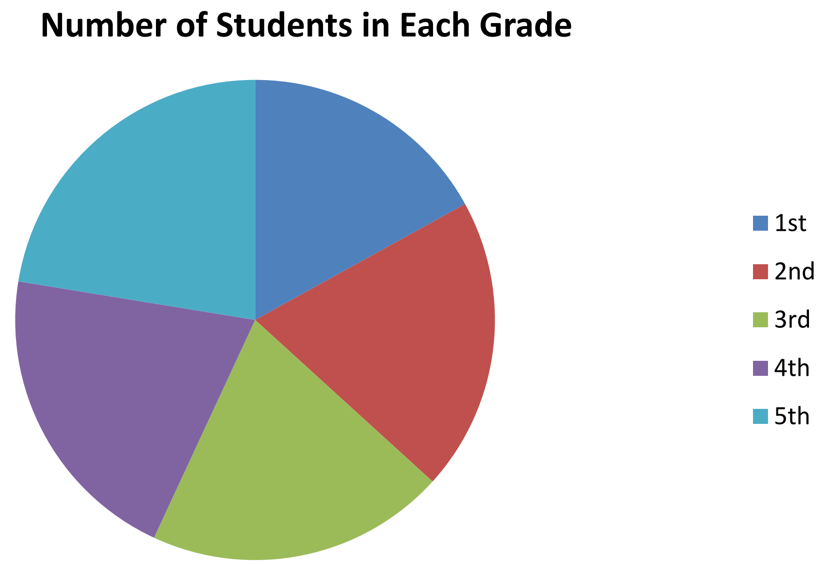
- *(Look at the vertical, or y-axis, labeled “Number of Students,”in the sample graph on page 4.   Notice the numbers as you read up the vertical axis. They begin at zero, each space is equally spaced, and the numbers increase by 100 at each interval.)*

Your horizontal axis, also called the x-axis, will indicate the names of the six different Kingdoms.

- Use the bar graph on page 4 as a guide.
- Notice the bars are the same width and they are evenly spaced across the graph.
- The bars are wide enough to see them clearly and to compare the height of the bars easily.
- Using the graph paper provided on page 11, decide how wide you want each bar and how much space you will allow between bars. Remember, your graph will have six bars.
- Use a ruler or straightedge to draw your y-axis and your x-axis. Leave enough space on the left side of the graph and at the bottom of the graph for your labeling.
- Draw your graph and label each part: x-axis, y-axis, scale, kingdoms, and title.
- Your labels should be clear enough so that anyone picking up your graph will know what it represents by just looking at what you have included in the picture!

Next we will make a **pie chart** for these data. A pie chart looks like a circle that has been sliced into sectors (pieces).   Because of this circular shape, pie charts are also sometimes called **circle graphs**. In a pie chart, each data category (in our case, the Kingdoms Animalia, Plantae, Fungi, Protista, Bacteria, Archaea) will be represented by a sector of the circle. The size of a sector’s interior angle is proportional to the fraction of the total data the segment represents. **Figure 2** on the following page provides an example of a pie chart.

Figure 2. This pie chart displays the same set of data for student number in different grades presented in the bar graph in Figure 1.



How to make the pie chart:

Step 1: Find the total number of species in all of the kingdoms.

Step 2: Find the fraction of the total number of species that belong to each kingdom.

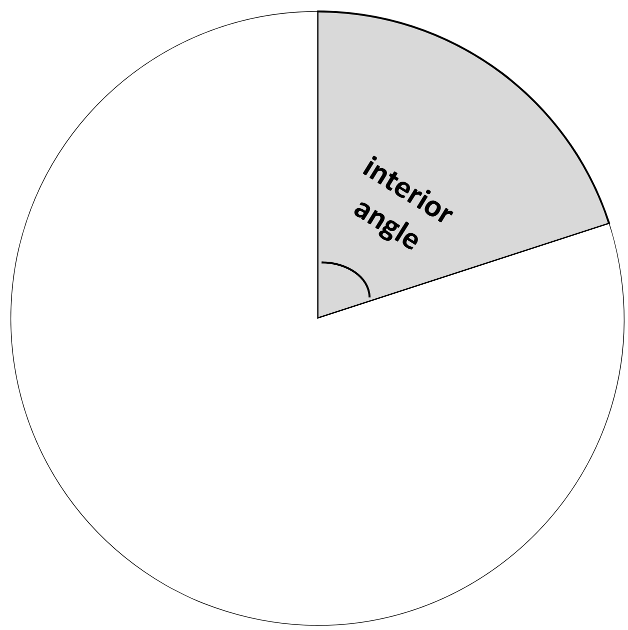
For example, if I have total of 32 candies in a bag and 8 of those candies are red, the fraction of red candies compared to the total is 8/32, or ¼ when simplified. You should have six fractions. The numerators of your fractions should have a sum equal to the denominator (the total number of species in all Kingdoms.

Step 3: Find the size of each sector's **interior angle**. Remember, you should have one sector for each kingdom, and the size of a sector's interior angle should be proportional to the fraction of the species that the sector represents, as follows:

$$\frac{\#\ species\ in\ \ kingdom}{Total\ \#\ of\ species} = \frac{degrees\ of\ sector's\ interior\ angle}{degrees\ in\ a\ circle}$$

Since a circle has 360 degrees, the interior angle of a sector representing a given kingdom can be calculated as follows:

$$° \, of \; sector's \;\; interior \; angle = \frac{\# \, species \; in \; kingdom}{Total \; \# \; of \; species} \times 360°$$



Since your fractions involve large numbers, you may wish to find the size of your circle sections another way. You could also find the decimal equivalent to your fractions and use that information to help you find the measures of your circle sections. Be sure to write down all the information as you work so you know which numbers relate to which kingdom. Using a calculator, divide the numerator of each fraction by its denominator. You now have a decimal number that may be several digits long. Round your decimal number to the hundredths place. Multiply that decimal number by 360 degrees. Round that number to the nearest whole number. Your answer will be the number of degrees of the circle for that Kingdom. Repeat the procedure for each of the six Kingdoms, being sure to write down your information as you find the degrees for each section.

For example, if you were making a circle graph using the candies example from Step 2, you could multiply the fraction representing red candies (1/4) by 360 degrees. One-fourth of 360 degrees is 90 degrees, so the section of a circle representing the red candies would measure 90

degrees. Note that by following the alternative procedure using the decimal equivalents of your fraction, you would still get the same answer. One-fourth is equal to 0.25, and when multiplying this number by 360, you would still get a measurement of 90 degrees.

<u>Step 4:</u> You will now use a protractor to draw the sectors of your pie chart. Your teacher may provide you with a template (found on page 12) to help you construct your pie chart. First, however, you should find the center of the circle. You can find the center by folding the circle in half, being sure the edge of the circle is exactly lined up with no overlaps (you may find it helpful to hold the paper up toward a light to help you see the circle edge). You may want to begin with a vertical (lengthwise) paper fold. Crease the paper when the edges of the circles are lined up correctly. Unfold, and then fold in a different direction in the same way you folded the first time, with the edge exactly lined up all the way around the edge of the circle. Crease the paper. When you unfold the paper, you should see a point where the two crease lines intersect inside the circle. That is the center point of your circle. Mark the center point with a pencil. Now, using a ruler or other straightedge, draw a line from the center point to any point on the edge of the circle. You will use this line to begin dividing your circle into sections. Your first interior angle is measured using the center point of the circle as the vertex of the angle, and the line you just drew as your base line. To construct additional segments of the chart, you can use each new line added for a kingdom as your base line for drawing the angle to represent the next kingdom that you add to the chart. Using your degree measurements you calculated from the fractions or decimals in Step 3, choose one of the six Kingdoms and measure its angle, making a mark on the edge of the circle so you know where to connect the line. Draw a line from the center of the circle to the mark you made at the edge of the circle to create the first section. Color the section and be sure to note the Kingdom represented by the color. Do the same for each of the other five sections, using a different color for each section. After measuring the fifth section, the remaining section should measure roughly the degrees appropriate for your sixth section (it may not be exact due to rounding the decimals earlier, but it should be very close).

<u>Step 5:</u> Create a legend or key to show the colors that represent each Kingdom. Use the example (Figure 2) on page 7 as a guide.

<u>Step 6:</u> Title your pie chart.

Alternative circle graph for younger students:

- Using your bar graph, measure one-inch wide strips of construction paper the length of each of your bars, using a different color for each Kingdom, and being careful to make your strips the exact length of the bars.
- Label each bar with the name of the Kingdom it represents.
- Tape the bars together end-to-end without overlapping the bars.
- Once all six bars are connected, complete the circle by taping the ends of the long strip together, end-to-end, without overlapping.

You can see from the different colors which Kingdom includes the most species and which has the least.

- Compare your circle to your bar graph, and answer the following questions:
  - What similarities do you see?
  - What differences do you notice?

Interpreting and comparing graphs

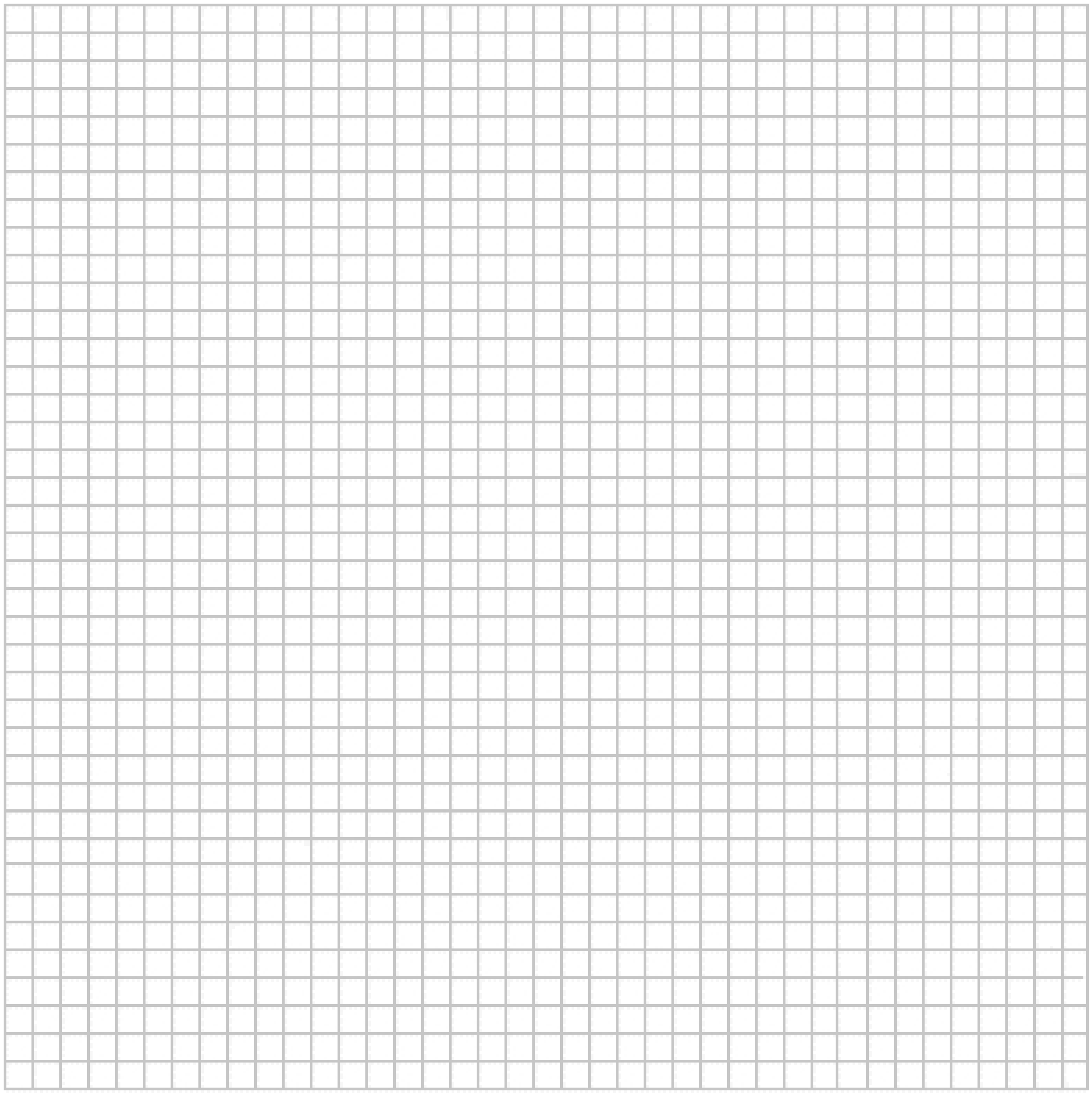
- When you have finished making your bar and circle graphs, compare them to the graphs located in the answer booklet under **Exercise 1**.
- Use the example graphs from Figures1 and 2 to answer the following questions.

Q1. Which grade has the most students? Which grade has the second most students? Which graph makes it easier to see the answer to this question?

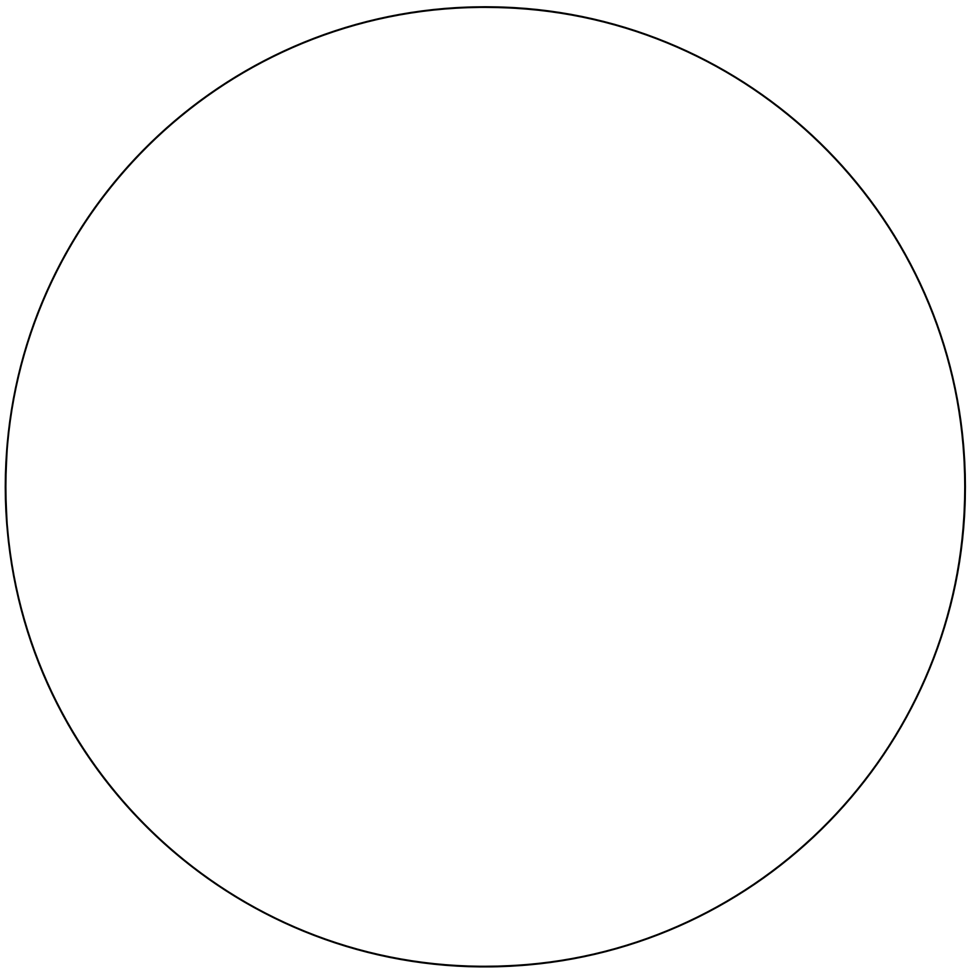
Q2. How are the students distributed among the five grades? That is, do a few of the grades contain most of the students, or are the students fairly evenly distributed amongst all of the grades?

Q3. Approximately how many students are in the third grade? Which graph did you use to answer this question? Could you have used the other graph to answer the question? Why or why not?

Q4. What kinds of questions are easier to answer by looking at a bar graph? What kinds of questions are easier to answer by looking at a pie chart?



Graph paper template for producing bar graph of Earth's biodiversity.



Template for producing pie chart of Earth's biodiversity

Exercise 2: What's that Reflection?: Animal Symmetry

This box contains a sample of the many different creatures that can be found in the **Kingdom Animalia**. Some of these organisms sure may not look like things you'd imagine when you hear the word "animal," but they are all members of the animal kingdom. All animals consist of many cells (are multicellular) and most (sponges are the exception) exhibit some form of body symmetry. This means they have a balanced distribution of duplicate body parts or shapes.

The kind of body symmetry an animal exhibits is important, since it helps us to understand its lifestyle. We can also use body symmetry and its pattern of development in identifying an animal's relationship to other animals. In the Animal Kingdom, there are two major types of symmetry that can be observed. In this exercise, you will learn about both types of symmetry, so that you can note whether each specimen in your sample is asymmetrical (lacks body symmetry) or has one or the other of the two major body symmetries, radial or bilateral.

- Some of the animals in the box exhibit a type of symmetry called **radial symmetry**. These animals have a central point about which they can be rotated without changing their appearance. Thus this radial symmetry is a kind of **rotational symmetry**. Think of a pie that has just been taken from the oven. You could rotate this pie on the counter any distance in either direction and it would look the same. It has a top (**dorsum**) and a bottom (**venter**), but you could divide the pie into two equal halves in any direction as long as you cut it through the center point.

    - Animals belonging to the phylum Cnidaria (hydras, jellyfish, sea anemones, and corals) exhibit a high degree of radial symmetry. Most cnidarians have a sessile life style. That is, they are anchored and cannot exhibit directed movement. Radial symmetry permits these animals to respond to stimuli received on any side with retreat into an exoskeleton they have secreted or the sand in which they are anchored.

Illustrating rotational symmetry:

- Take a square object (square pattern block or square piece of paper, for example) and trace around the outer edge (perimeter) on a larger piece of paper.
- Keep the object in place so that it is still in the position it was in when you traced the shape.
- Make a mark on one edge of the square (the top, for example), so you can keep track of that particular edge.
- Place a finger on the shape at its center and hold the shape firmly enough that it remains in place without sliding across the paper, but also so you can rotate it with your other hand. Turn the object just until the shape fits into the traced edges again. Do not move or slide the shape, only rotate it while your finger holds it at the center.
- Turn it another time until it fits into traced edges again.
- How many times can you turn the shape so that it fits into traced edges before you make one complete circle around the traced edges? What you have just demonstrated is the square's *rotational symmetry*. The shape can be rotated four times and still look exactly the same. It was not moved to a different location, only turned about the center of the shape.

Finding the degree measure of rotation of radially symmetrical objects:

To find the degree measure of rotation of an object, you will think in terms of the 360 degrees in a circle because we are investigating the circular rotation of the object. For this exercise, your teacher will provide you with a piece of graph paper with an x-axis and y-axis drawn on the paper and with a circle drawn on the graph with the center of the circle at the origin.

- Notice that the x- and y-axis have divided the circle into four equal sections called **quadrants**. (*Quad*- is a prefix meaning *four*.)

Because of the unique properties of circles, we measure circles in **degrees** rather than other units we use for measuring distances or other amounts (like centimeters or liters). One complete circle has 360 degrees.

- Look at the circle on your paper, and think about the following questions:
  - If the x-axis and y-axis divide the circle into four quadrants, how many degrees of the circle are in *one* of the quadrants on the graph?
  - Looking at just one of the quadrants on your graph and thinking about the number of degrees in that one quadrant, how many degrees does *one-half* of that one quadrant represent?

If your answers to the previous questions were that one quadrant contains 90 degrees of the circle, and that one half of a quadrant represents 45 degrees, you are exactly right!

Now, you will use the square object you used in the previous illustration of rotational symmetry to see how you can quantify (measure) the degree of rotational symmetry possessed by an object.

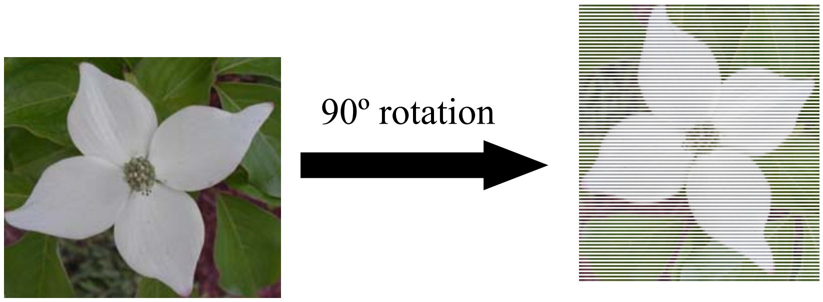
- Place your square object on the graph paper so that the center of the square is at the origin and the top and bottom of the square are parallel with the x-axis.
- Trace the square.
- With your finger at the center of your square (at the origin!), rotate the square until it fits into your traced edges as you did in the previous illustration.

How many degrees did you turn the square before it fit into the traced edges? The center of the top edge of your square was originally in line with the y-axis, and now it is in line with the x-axis. Use your finger to trace the path of the rotation of that center point of the top of your square. How many degrees did it rotate? The square is said to have *90 degree rotational symmetry* because it rotated 90 degrees before fitting into the traced edges again.

- Look at the pictures of the dogwood flower on the following page.

The dogwood flower has rotational symmetry, because we can rotate the flower about its center by 90 degrees (or a multiple of 90 degrees), and it will look just like it did before we rotated it.

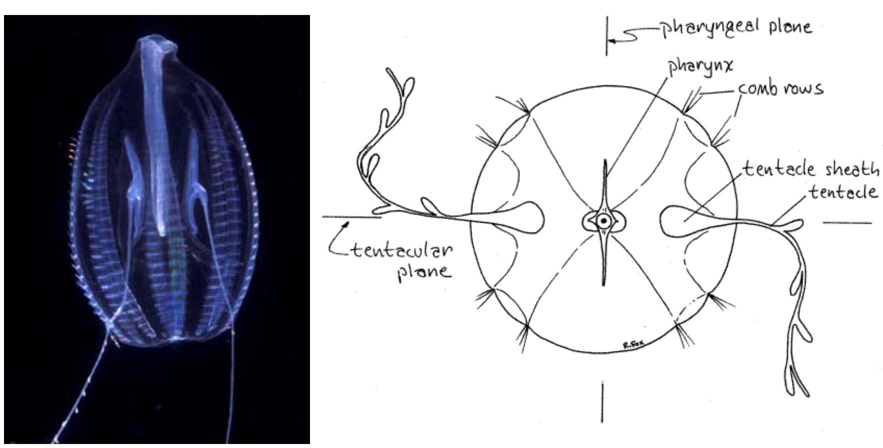
The dogwood flower below has a form of rotational symmetry. If we rotate the dogwood flower about its center by 90° $\left(\frac{\pi}{2} \text{ radians}\right)$, or a multiple of 90 degrees, it will look just like it did before we rotated it.



This flower demonstrates the idea that to have rotational symmetry, it is not necessary that *any* rotation position preserves the object's appearance, as in our pie example, but that there is more than one rotation that preserves its appearance. If a shape only matches itself **once** as you go around (i.e. it matches itself after one full rotation) there is really no rotational symmetry present. As defined, symmetry comes from the Greek words "*syn*," meaning 'together' and "*metron*," meaning 'measure'. For an object to have rotational symmetry, there must be at least two identical parts that 'come together' at a central point. It is important to note that because cnidarians possess tentacles, they do not have the same degree of rotational symmetry of the perfectly formed pumpkin pie. Many (sea anemones and corals) do, however, have a greater degree of rotational symmetry than the dogwood flower shown above.

Q1. How many rotational positions preserve the appearance of the dogwood flower? What are those positions, in terms of angles?

Q2. How many rotational positions preserve the appearance of the comb jelly or sea walnut shown below?



Q3. Find all of the angles of rotation less than 360° that preserve the appearance of the sea urchin skeleton below.

You are now going to investigate another type of symmetry called **bilateral symmetry**. Bilateral symmetry is also sometimes called **line symmetry**, **reflection symmetry**, or **mirror symmetry**. If an object can be folded along one line so that the two sides fold right onto each other without any gaps or overlaps, the object is said to have *bilateral symmetry*. The prefix *bi-* means two (for two sides), and the root word *lateral* refers to having sides, so you have two sides divided by a line that match each other when folded along the line so that the sides match with one fitting exactly onto the other.

Illustrating bilateral symmetry:

- Take a sheet of paper and fold it in half.
- With the paper folded in half, cut a shape out of the folded paper.
- After you have cut the paper, open the folded paper.
- Notice the fold line going through the middle of your shape.

The fold line on your object is a *line of symmetry*. You have just created a shape that has *bilateral symmetry*, because you have two sides of your shape that can be folded one onto the other along the fold line without any gaps or overlaps. This type of symmetry is also called *mirror symmetry*, because one side is a *mirror image* of the other. If you were to stand a mirror along your fold line with the mirror facing you, the image of your shape that you see in the mirror will look like the other side of your shape. The two sides are the same, but face different directions. Mirror symmetry is also called *reflection symmetry* (you see your *reflection* when you look in a mirror).

- Examine this picture of a butterfly.

- If we were to draw a line down the middle of the butterfly, the parts of the butterfly to the left and right sides of the line look the same, only they are facing opposite directions. In other words, this butterfly displays **bilateral symmetry**. Both the left and right sides have a front and hind wing, an antenna, an eye, and three pairs of legs. Internally, there is also duplication of body parts on the left and right sides (e.g., muscles, reproductive structures, excretory organs, and nerves). Because a bilaterally symmetric organism has mirror-image left and right sides, it is said to have **reflection symmetry**. Imagine that the line separating the two identical sides is the edge of a blade going straight into the image. The flat surface of that imaginary blade that separates the two identical sides is called the **plane of symmetry**. Bilaterally symmetrical organisms can only be divided into two equal halves (right and left) by ***one*** plane of symmetry, which runs down the midline of the animal between its front and rear ends (as opposed to multiple planes of symmetry seen in radially symmetrical organisms). You should be able to fold a picture of a bilaterally symmetric animal and have both halves match exactly because of its reflection symmetry.

    - Bilateral symmetry in animals is associated with a more active lifestyle, in which individuals need to exhibit directed movement towards and away from various stimuli. For instance, predators need to follow prey, and prey need to move away from predators. Bilateral symmetry is associated with the concentration of nerve cells at the anterior end of the body in the form of a brain. Stimuli received by sensory nerves on the right and left sides of the body are processed in the brain, and messages sent to the appendages through motor neurons. Directed movement is thus achieved.

Q4. Does the dogwood flower on page 16 also have reflection symmetry? If so, how many planes of symmetry does the dogwood flower have?

- Separate the animals in the box according to the type of symmetry that they display: bilateral symmetry, radial symmetry, or no symmetry (asymmetrical). If an organism displays radial symmetry, note how many planes of symmetry are present.

Exercise 3: Guess that Phylum

Exercise 3a: Guess that Phylum (*for lower grades*)

In this exercise, you will learn about all kinds of animals, and the traits that scientists use to classify animals into groups. Each of the nine major groups of the animals you will learn about is called a phylum. Using the directions below (and your teacher's help, where needed), you will play a game that will help you learn more about the types of animals in each of these groups. Your job in this exercise is to try to match each of the animals in this box to the pictures of other animals belonging to the same phylum.

- Divide the class into groups of 3-4 students each .
- Each group should briefly examine all of the organisms in the box spread out on a table at the front of the room. Students should try to identify similarities and differences between organisms as they examine them, as this will assist them in the game they will be playing .
- Your teacher will randomly determine the order in which each team will take their turns (the teacher could use the provided spinner to spin a number for each group to determine turn order or draw numbers).
- For each turn, the teacher should display one of the picture sheets of an animal phylum (either a hard copy or using the PowerPoint version of the sheets). Students in the selected team should examine the organisms in the pictures, and try to see if they can find an organism from the box that belongs to that animal phylum. The students in the team should tell the class why they think the animal they selected belongs to that phylum: discuss similarities between their chosen organism and the pictures that led them to this conclusion.
- Once a team has presented its decision to the class, the other teams can be consulted to see if they agree with all of the choices made by the focal team.
- In the end, the teacher should check the decision and lead a discussion of why a wrong choice might have been made: why a particular animal does not fit into that group.
- The teacher may share additional information about each of the animal phyla from the backs of the picture sheets, or have the students read this information to the rest of the class.
- Repeat these steps until all of the specimens have been properly assigned to the correct phyla.

Exercise 3b: Guess that Phylum (*for higher grades*)

In this exercise, you will learn about a number of traits that distinguish animals, belonging to the "Big Nine" phyla. There are a total of over 30 animal phyla, but over 95% of described animal species belong to the nine phyla represented by the specimens in this unit. Thus, in learning to recognize the characteristics of these phyla, you will learn a lot about the majority of the animals here on earth!

- Divide into teams of no more than 4 students each.
- Your teacher should have placed the animals from the box at several stations around the room. There should also be a station in a central area with no organisms, but with labels displaying the names of each of the "Big Nine" animal phyla.
- Each team should visit the stations and examine the animals, making notes about their structure. Things to consider: How are they alike, and how are they different? Record your observations on a sheet of paper. Your team will use these notes to play the game described below.
- Your teacher will randomly determine the order in which each team will take their turns.
- At the start of a turn, a team will spin the spinner. If the arrow lands on a number between 1 and 9, you will read the corresponding description of the basic body plan of an animal phylum from the table on page 23.
- Using the information from the table, as well as your notes, the team should decide on an organism that you believe belongs to that particular phylum, and place this animal in the appropriate labeled area in the central station. The team should also present to the entire class the organism they have selected, and their reasoning for selecting that particular organism as a representative of the phylum indicated by the spinner. (Your teacher may have images of the organisms displayed for the class via projector to make this easier for everyone to see.)
- A scribe (either one from each team, or one individual) should keep track of which organism each team has selected to belong to a particular phylum on each turn, and write this information on the blackboard.
- The next team should then take their turn, repeating the previous step.
- Once all of the organisms of a particular phylum present have been taken, a team landing on that phylum loses its turn.
- If a team gets a result of 0 on the spinner, they may choose to either spin again to try to obtain a new phylum, or take an organism another team has assigned to a phylum and move it to where they feel it correctly belongs.

- Once all of the organisms have been assigned to phyla, check your results on the answer sheet at the end of the book. The scribe should circle the correct answers on the blackboard and cross out the incorrect ones.

Below are some questions that you can use in starting a class discussion on phylogenetic relationships among animals.

  - Were there any animals that were difficult to assign to a particular phylum? Why do you think this was the case**?**
  - Which phylum was the easiest to identify? What characteristics of the animals in the box made it clear that they belonged to that particular phylum?
  - Were there any animals that were incorrectly assigned to a phylum by a team at any point? If so, what characteristics did they have that made it tricky to assign them to a particular phylum?
  - Were there phyla that were difficult to distinguish from one another? Why?

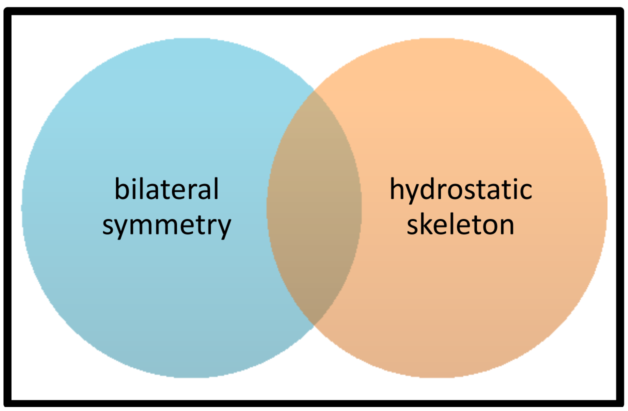
- After you have completed the game, take some time to look over the *Study Sheets to the Major Animal Phyla* and gain some additional information that may further help you distinguish among these phyla.
- You should also examine the pictures provided of additional organisms belonging to each phylum. These will help you recognize similarities between organisms within each phylum, as well as to get an overview of the diversity present in each phylum.
- You should then complete another round of the game to see if your teams can improve their scores, as well as their strategies!

Table of animal phyla used for spinner results in the "Guess that Phylum" game.

Spinner Result	Phylum and Basic Body Plan
0	**SPIN AGAIN OR STEAL!**
1	**PHYLUM ANNELIDA:** Elongated body comprised of many similar segments
2	**PHYLUM ARTHROPODA:** Body composed of several main regions (each of which may be made up of multiple fused segments); covered with a protective exoskeleton; possess paired jointed appendages
3	**PHYLUM CHORDATA:** Organisms that possess all of the following at some point in their development: gill slits, a notochord (a flexible, rod-shaped "support system"), a dorsal hollow nerve cord, and a tail that extends past the anus
4	**PHYLUM CNIDARIA:** Sac-like bodies which may take one of two basic forms: a free-swimming umbrella-like shape or a tube-like sessile form; both with tentacles with stinging cells
5	**PHYLUM ECHINODERMATA:** Adults display radial (rotational) symmetry; unsegmented; covered with a hard exoskeleton often with a spiny/bumpy surface
6	**PHYLUM MOLLUSCA:** Soft yet muscular bodies that may also possess an internal or external shell
7	**PHYLUM NEMATODA:** Cylindrical/tubular bodies tapered at both ends, with openings of the digestive tract at each end; covered with a resistant cuticle
8	**PHYLUM PLATYHELMINTHES:** Flattened, non-segmented bodies that display bilateral (reflection) symmetry
9	**PHYLUM PORIFERA:** Asymmetrical organisms that resemble a tube closed at one end, with many small perforations (holes) in the body wall

Exercise 4: Diagram those Traits

Now that you are familiar with some animal traits, you can construct a **Venn diagram** to demonstrate pictorially the relationships among traits. A Venn diagram looks like a rectangle with some circular regions inside of it. The rectangle represents a set of possible items. In our case, the rectangle will represent all animals. The circular regions represent specific items or specific sets of items that belong to the total set of possible items. For example, in the Venn diagram below, one of the circles represents animals with bilateral symmetry, and the other represents animals with a hydrostatic skeleton. If two regions overlap, then there are some things that belong to both regions. For example, the region of overlap in the diagram below represents the animals with both bilateral symmetry and a hydrostatic skeleton.



Regions that have nothing in common will be separate. On the other hand, if all things in region A also belong to region B, then region A will be completely contained in region B. **Do note, however, that:**

- **The size of a region does not indicate how many things belong to the region!**
  - For example, the fact that the hydrostatic skeleton region is about the same size as the bilateral symmetry region in this diagram does *not* mean that there are about as many animals with hydrostatic skeletons as there are animals with bilateral symmetry!
- **You could have more than two circles or other shapes within the limits of the Venn diagram (each representing different characteristics)!**
  - For example, you could have another circle designated to represent radial symmetry somewhere within the rectangular region.
- **Some circles could fall entirely within others.**
  - For example, animals that exhibit some form of segmentation all have bilateral symmetry, but not all bilaterally symmetrical animals have body segmentation, so if we were to add a circle representing segmentation, it would be completely inside the circle representing bilateral symmetry!

Use the *Study Sheets to the Major Animal Phyla* to answer the following questions:

Q1. Which of the following animals belong in the region of overlap in the Venn diagram on the previous page?

a) Hydra
b) Roundworm
c) Insect

Q2. Which of the following animals belongs in the non-overlapping blue region only?

a) Hydra
b) Roundworm
c) Insect

Q3. Draw a Venn diagram with regions to represent animals with the following traits: jointed legs, radial symmetry, nervous system, tissues. Which of these regions contains the most animals?

Q4. Several pairs of regions are listed below. Use the diagram which you just created to decide which member of the pairs below contains the most animals, or else state that this cannot be determined by looking at the diagram.

radial symmetry or nervous system

jointed legs or radial symmetry

nervous system or jointed legs

- Now pick some traits that interest you, and construct a Venn diagram to show how they are related.
- **For a "Super Solver" challenge, come up with a Venn diagram that includes all nine phyla represented in this box!**

Exercise 5: Sort these Animals (Grades K-2)

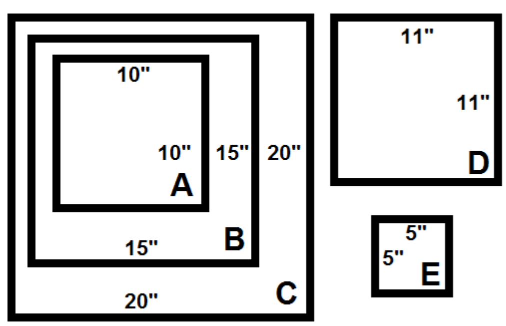
This exercise provides a framework in which younger students can explore the similarities and differences among the major animal phyla. This exercise incorporates elements from both the "Diagram those Traits" and "Who's in that Tree?" exercises for older students. Teachers may use one of two approaches (identity-based or trait-based) to introduce the concepts of classification, as well as relationships among groups of animals, both involving interactive, teacher-mediated discussion. The class might complete the exercise based on identities first and then try it using traits as a mechanism of formative assessment of what they have learned. An open-ended exploration of the topics is also presented.

Materials Needed

- Representative animal specimens from this box
- Tape

Instructions

- Use tape to mark out the rectangles diagrammed below either on a table or on the floor. Approximate suggested sizes for each rectangle are provided. Label each of the rectangular areas with a letter, as shown.



- Either randomly assign a specimen from the box to each student in your class, or allow each student to come up and select an organism from the box. If you have more students than specimens, you may wish to have students pair up to share an organism.
- After all the specimens have been assigned, explain to the students that they are going to be scientists for the day! Let them know that biologists like to group similar living things together and think about how different organisms might be related to one another. You may also wish to mention that very often, organisms

that are closely related look similar to one another. However, organisms that look similar may not always be necessarily very closely related.

- Have your students examine the diagram of rectangles within rectangles that you have laid out. Explain that these rectangles are going to represent a way of grouping animals based on similarities, and that each rectangle represents a trait or characteristic of an animal. Let them know that if an animal is inside a rectangle that is inside another rectangle, that animal has traits all rectangles have that contains it.

Exercise 5a: Sort these Animals (Identity-based)

- Have your students look at their specimens and note the number and/or letter on their respective specimens.
- Have each one place his or her specimen inside the set of rectangles using the following guidelines:

    - Students with specimens 7, 10, 16, and 22 should place their specimens in rectangle A.
    - Students with specimens 6, 13, and 17 should place their specimens in rectangle B.
    - Students with specimens 3, 4, 5, 9, 11, 14, 18, 19, 21, and 23 should place their specimens in rectangle C.
    - Students with specimens 2, 8, 12, 15, and 20 should place their specimens in rectangle D.
    - The student holding specimen 1 should place it in rectangle E.

- After all students have placed their specimens in the appropriate rectangles, take a few moments to have them examine the organisms in each one sequentially, and try to see if they can figure out the traits that those organisms have in common. Remind them that rectangle B also contains rectangle A, and rectangle C contains both rectangles A and B! The correct answers are shown on the following page.

Rectangle A: All of these organisms have paired jointed legs and a tough exoskeleton.

Rectangle B: The bodies of all of these organisms are comprised of distinguishable segments.

Rectangle C: All of these organisms have bilateral (reflection) symmetry. In other words, a single line could be drawn down the middle of each of these organisms, which would divide them into identical, mirror image left and right halves.

Rectangle D: These organisms all have radial (rotational) symmetry. Another way of explaining this to students is to imagine placing a dot right in the middle of the organism. There are several ways to cut outwards from this center point that would divide the animal into multiple parts that all look the same, much like cutting pieces of a pie.

Rectangle E: This organism is the most different than all the others, as it is not symmetrical in any way, and does not have any of the specialized structures listed above.

Exercise 5b: Sort these Animals (Trait-based)

Mention each of the traits listed for a particular box above. Then ask students to examine their specimens, and to place them in that box if they think their organism matches that description. Go over the students' choices for each box, and check to see that they are correct. If there are any incorrect answers, or any organisms left out, let the students know the correct answer, but have them try to figure out why an organism does or does not fit into that box.

Exercise 5c: Sort these Animals (Open-ended Expansion)

Explain to students that different scientists often use different characteristics to categorize organisms into groups. Allow students to work together in small groups to try to think of alternate ways of grouping together the provided specimens, based on characteristics that they observe (such as size, color, the way the animals would have moved when alive, habitat, etc.), and have them draw a system of boxes showing how they decided on these groupings. You could have non-readers draw pictures of their organisms in the appropriate boxes, or print pictures of the organisms for them to cut out and glue in these boxes.

Exercise 6: Who's in that Tree?

Even though you have already been introduced to the major "traditional" classification system of organisms, biologists also use another method of classification, called **cladistics**, which is an attempt to think about the shared histories of organisms, or how they are related. **Phylogenetic trees**, or **cladograms**, are graphical representations of hypothesized evolutionary relationships among organisms. They reflect the history of organisms. In understanding phylogenetic trees, it will help if you think about how an actual tree grows: from the roots up (sometimes phylogenetic trees are presented sideways, but you should still be able to distinguish a trunk and the direction of the branching in that case). The roots of a tree represent the oldest part of a tree, and the tips of the branches represent the newest parts of the tree. In other words, when you examine a phylogenetic tree from the root to the tips of the branches, you are looking forward in time from the past. You will also notice that there are points where two branches arise from a common point on the tree. That common point is known as a node, which represents an ancestor of the two organisms or groups of organisms from that point. This splitting off into two (or sometimes more) branches from an ancestor represents speciation which is the formation of new species or groups of organisms from that ancestor. It is important to note that in this context, "ancestor" does not refer to a single organism, but a population of organisms that gave rise to the new lineages.

Note that some of the nodes on the tree have a circle on them with a number inside. This represents a trait that appeared in an ancestral population that was then passed on to its descendants. In general, once a new characteristic develops at a particular node, all of the organisms located on the higher branches of the tree have the new characteristic.

- Examine the tree on page 31.
- Find the circled node labeled 1. It represents multicellularity, the condition of being made up of multiple cells. You can see that all of the phyla represented on the tree branch beyond this point are multicellular organisms.

The jellyfish and corals (phylum Cnidaria) branch off the tree at the node labeled "2". In addition to being multicellular, their cells are specialized into **tissues** that perform different bodily functions. **Ectoderm** is one of three types of tissue that the higher animals have. Ectodermal tissue forms the boundary layer between the contents of an animal's body and the external environment. Ectodermal tissues also provide structural support. Skin, hair, feathers, fur, and bones are examples of ectodermal tissue. The stinging cells of jellyfish and corals are also ectodermal. Another tissue found in this animal group and all higher animals is **endoderm**, which is involved with the digestion of food. The guts of all animals located above the sponges on the tree are lined with endodermal tissue.

Some organisms have ensembles of various tissue types, called **organs**, that work together to perform specific functions. Flatworms (phylum Platyhelminthes) were the first organisms to have organs, in the form of primitive kidneys that remove waste. The animal groups whose branches arise from the node labeled "3" on the tree or above that point have some form of a kidney. Other organs, such as the heart, lungs, and liver first appear in animal groups that are located further up the phylogenetic tree. These organs become increasingly complex in the higher branches of the tree.

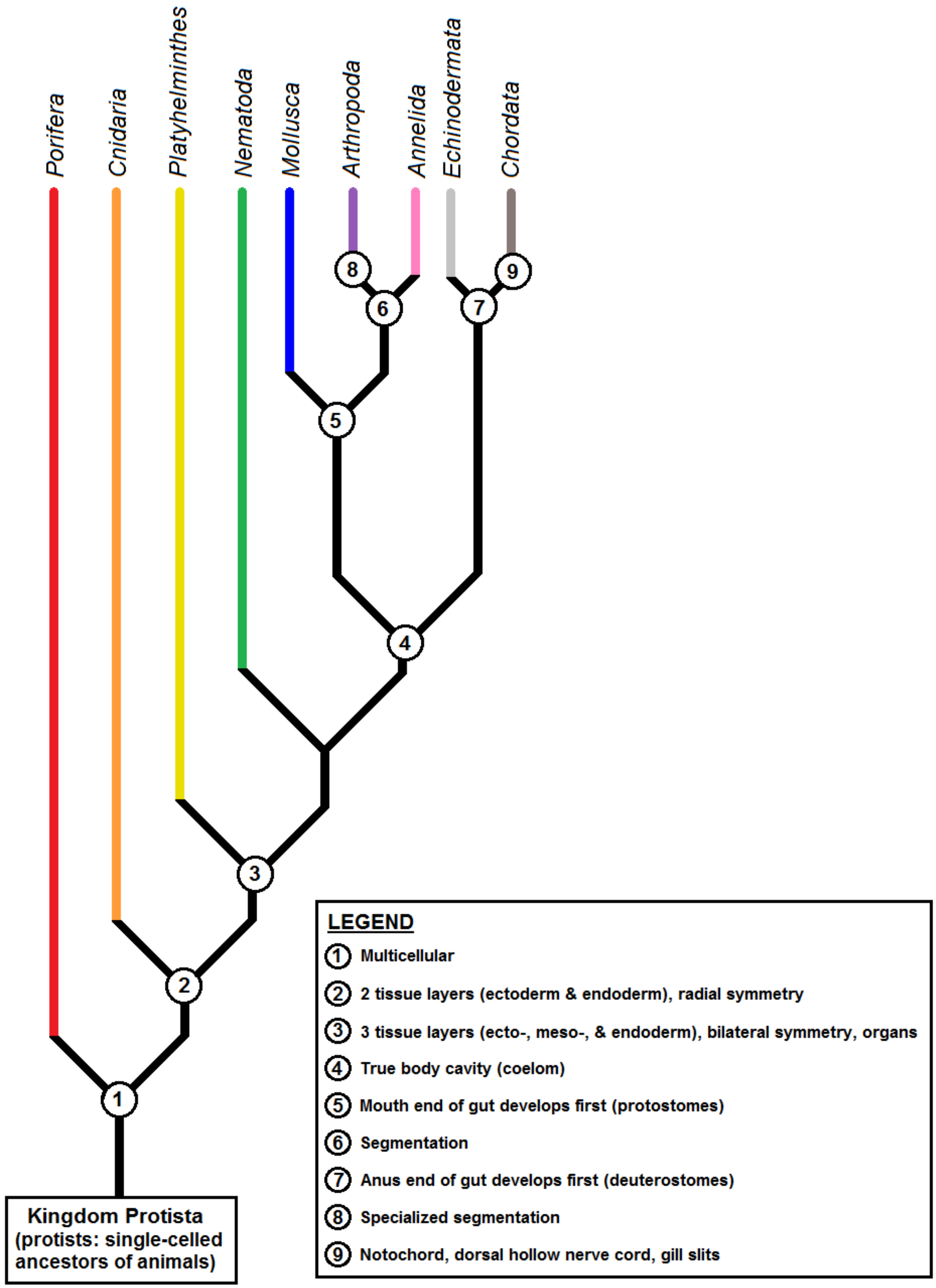
Each branch (or lineage) has an ancestor, but there are also ancestors farther back in time that that each lineage (group of organisms) shares with other lineages. For example, the circle labeled "8" on the tree represents the ancestor of the modern arthropods (insects and their relatives), and the node labeled "6" represents the **most recent common ancestor** of both arthropods and annelids (segmented worms). The more recently two particular groups share a common ancestor, the more closely they are related. For example, the annelids are more closely related to the arthropods than they are to the chordates, a group that includes the vertebrates. The annelids are also related to the chordates, just more distantly, as the common ancestor that they share is farther back in time.

- Which node represents the most recent common ancestor of arthropods, annelids, and molluscs?
- If you said the node labeled "5", then you are correct!

The phylogenetic tree shows how new types of animals come into existence as animals change and develop (evolve) over time. As a result of this evolution, today there are over 30 different basic animal body plans. These plans are called phyla of the Kingdom Animalia.

NOTE: Though some organisms may seem "simpler", it is important to realize that none of these groups is "more evolved" than other groups of modern organisms, as each group is the result of its own evolutionary path over millions of years towards their respective body plans that have allowed them to successfully survive in the environments in which they are found.

Figure 1. This phylogenetic tree shows the historical relationships that exist among the nine major different body plans, or phyla of the Kingdom Animalia.



Exercise 6a: Understanding Historical Relationships

Now that you know how phylogenetic trees work, see if you can determine where all of the animals in your box go on the tree.

- Carefully study Figure 1 on the previous page, noting the changes in body plan that are associated with each branch, and the animal group(s) that is/are associated with the development of new features.
- Find the poster of the phylogenetic tree. The branches of this tree are labeled with the traits they represent, but are not labeled with the animal groups that belong on the branches.
- Lay the poster on a flat surface and place each specimen on the tree branch where you think it belongs. Do not refer to Figure 1. We have provided a key to the tree on the following page. Each color represents a set of characteristics that an animal must possess in order to fit on that branch.
- Use this key to help you place your animals on the appropriate branch of the tree.
- Be sure to check your animal positions on the poster against the smaller diagram (Figure 1) and the answer sheet at the end of the book (and/or the *Study Sheets to the Major Animal Phyla*) when you have finished. How did you do?

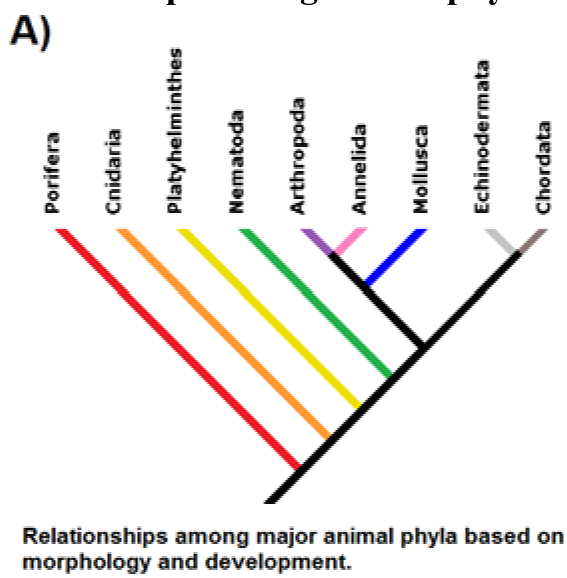
Key to the branch colors on the poster and Figure 1.

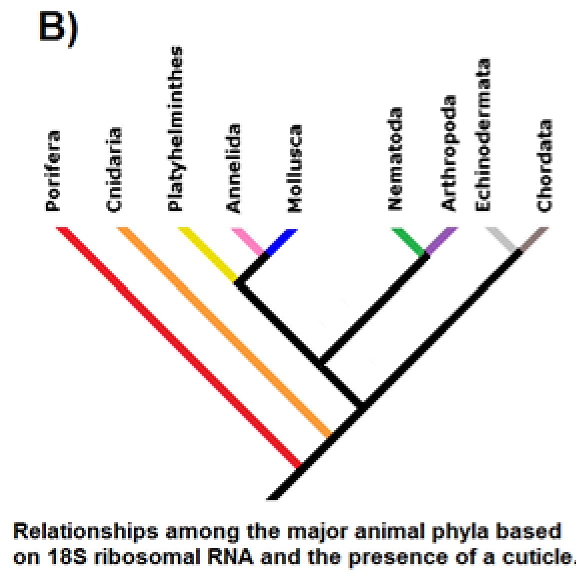
Branch color	Characteristics shared with ancestors	Characteristics passed up the tree	Additional characteristics
Red		multicellular	filter feeding, sessile
Orange	multicellular	tissues (ectodermal & endodermal)	stinging cells, radial body symmetry
Yellow	multicellular, three tissues	bilateral body symmetry, organs	primitive kidneys, thin body
Green	multicellular, three tissues, organs, bilateral body symmetry		false body cavity filled with fluid to maintain tubular body-shape
Blue	multicellular, three tissues, organs, bilateral body symmetry	true body cavity that houses organs	shell
Pink	multicellular, three tissues, organs, true body cavity, bilateral body symmetry	mouth end of gut develops first, segmented body	many segments give a "ringed" appearance
Purple	multicellular, three tissues, organs, true body cavity, bilateral body symmetry, mouth end of gut develops first		reduced number of body segments, external skeleton and muscled limbs
Gray	multicellular, three tissues, organs, true body cavity, bilateral body symmetry	anus end of gut develops first	larvae are bilaterally symmetrical, but adults can be divided into 5 equal pieces around a central point; external skeleton
Brown	multicellular, three tissues, organs, true body cavity, bilateral body symmetry, anus end of gut develops first		Possess all of the following at some point in the life cycle: notochord ("skeletal" support rod), dorsal hollow nerve cord, gill slits, muscular post-anal tail

Exercise 6b: Comparing Phylogenetic Trees

- There are often many different scientific hypotheses as to how a system functions.   Figure 2 shows two competing hypotheses as to how the higher invertebrates are related to one another. Examine the trees in Figure 2 to see how they are different.

Figure 2. Comparison of two different proposed branching patterns for relationships among animal phyla.





- Find examples of the animals that belong to the phyla that are represented in Figure 2.

- Now compare the lineages shown in Figure 2 to the phylogenetic tree in Figure 1.

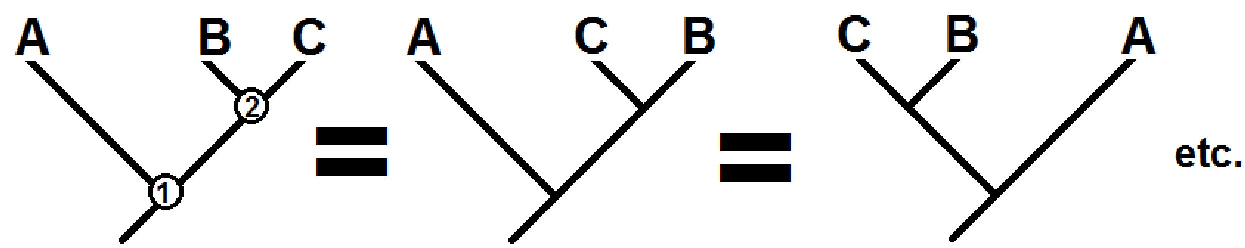
Note that the tree on in Figure 2A, (based on patterns of animal development) is the one that you have been using in Figure 1. For quite some time, this has been the most widely-accepted hypothesis regarding the relationships amongst the major animal phyla. The tree in Figure 2B was first hypothesized in 1997 (Aguinaldo et al. 1997) to explain the results of the molecular analysis of one gene system. According to this new tree, the animals possessing a skin covering called a cuticle that must be periodically shed during growth are more similar in their genetic makeup than the animals lacking this cuticle.

- Answer the following questions. Consult Exercise 3 in the answer booklet to check your answers.

Q1. Which animal groups are displaced in the tree depicted in Figure 2B from where they are located in the tree based on development (Figure 2A)?

Q2. How might the validity of the two alternative trees be tested?

IMPORTANT NOTE: When interpreting phylogenies, it is important to recognize trees with **equivalent topologies** (the same branching structures). Phylogenies with equivalent topologies show the same relationships, but may look slightly different. ***On any given tree, switching positions of branches that arise from the same node, or rotating parts of the tree around a node does NOT change the relationships shown by the tree.*** See below for an example.



In the second tree above, the branches representing B & C have just switched places at the node labeled "2" in the first tree. The third tree just depicts a rotation of branches around the node labeled "1" in the first tree. All of these trees still show the same relationships, because in all of these trees, B & C are **sister taxa**, and the group consisting of B & C is the sister taxon to A. In other words, all these trees have equivalent topologies.

Exercise 7: What is that Animal?

In the box, you should find an animal with no number, labeled as the "Mystery Animal". Given what you have learned in the other exercises in this unit, place this animal with its nearest relatives on the tree. To which phylum do you think your mystery animal belongs? What traits do you notice on your mystery animal that led you to make this decision? Check the answer sheet for Exercise 7 to see whether you were correct.

Exercise 8: Pass that Gas!

Numerous science fiction movies have been made with the theme of gigantic insects terrorizing the human populace. The images in Figure 1 are good examples of such films.

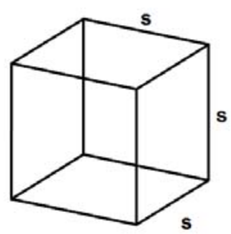
Figure 1. Giant insects in science fiction movies. Left: from the 1954 movie *Them!*; Right: from the 1957 movie *The Deadly Mantis.*

Such films play on the fear of insects shared by many people, but are horribly scientifically inaccurate. Though some insects can be dangerous, it is simply impossible for insects to ever get large enough to tower over people or to crush cars. Why do you think this is the case?

- Take a few moments to brainstorm about possible biological reasons behind why insects cannot get so large.
- Your teacher should make a list on the board of possible reasons that you and your classmates come up with as to why insects of such size are not possible.
- After your teacher has compiled a list of reasons why there are no insects as large as the humongous ones in science fiction and horror movies, take a few extra minutes as a class to discuss each of these hypotheses. Do some seem more reasonable than others? Why or why not?

Now that you have taken a bit of time to think about this problem, you'll explore one important biological factor behind the absence of such huge insects in today's world. This is a cell's or organism's surface to volume ratio. All cells and organisms need to get materials into them and remove waste products out of them. It is the surfaces of cells and organisms that represent interfaces between them and their respective environments. For example, a cell obtains nutrients and oxygen, absorbs heat and releases carbon dioxide through its cell surface. On the other hand the volume of a cell (or organ, or an entire organism) represents available space for storage of resources (in the form of fats, starches, etc.), as well as space in which important physiological reactions can take place. The volume of a cell thus determines how much oxygen is needed to accomplish physiological functions as well as how much carbon dioxide needs to be released.

Thus, both the surface area and volume of an organism or a cell are very important parameters. What is critical to limiting insect size is a limiting factor to cell size as well. This is because at differing sizes of the same shape, the relationship between the amount of surface area and volume changes. We can use simple shapes, such as cubes and spheres, to illustrate this fact. First, consider a cube with sides of length s. Since a cube is composed of six square faces (each with sides of length s), the surface area of a cube is equal to $6s^2$. The volume of the same cube is equal to its width times its length times its height (all of which are also equal to s), so the volume of a cube is equal to s^3.



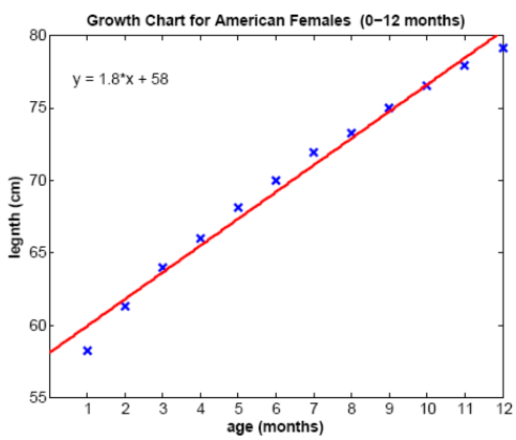
- Complete the table below, calculating the values of surface area and volume for cubes of a given side length.

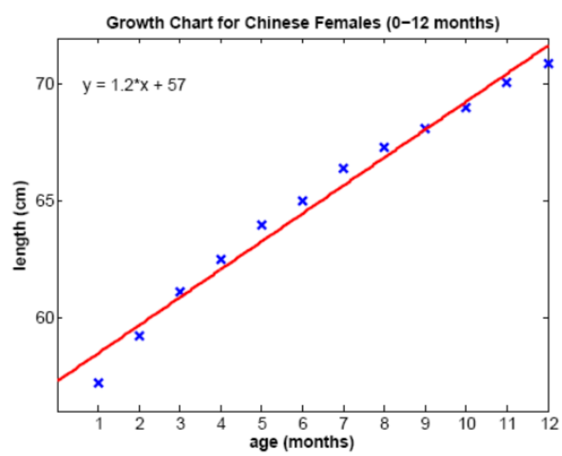
Side length of a cube (in units)	**Surface area of the cube (in units^2)**	**Volume of the cube (in units^3)**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

- Check your calculations in your table against those presented under **Q1** in the answer section of this unit.
- Next make a plot of these data, with the surface area of the cube on the x-axis, and the volume of the cube on the y-axis. This is called a scatter plot. If you have not completed this type of plot, instructions for doing one are provided below.

About Scatter Plots

The graphs below are examples of a scatter plots. Scatter plots are used to explore possible relationships between two variables (cell surface area and volume in our case) that both relate to the same phenomenon (cell size). By convention, the independent variable (if one is identified as such) is positioned on the x-axis and the dependent variable (the trait you are questioning) is placed on the y-axis.





In each figure above, body length is plotted against infant age. We used Matlab to draw the 'best fit' line through the scatter plots. What can we see from the figures? Body length in both American and Chinese female infants is correlated with age. However, the data points for American females tend to lie above those for Chinese females. This is reflected in the fact that the best fit line for the American data lies above that for the Chinese data. This suggests that American female infants are, in general, longer than Chinese female infants. Why might this be the case?

NOTE: Since your graph is not based on collected data, but rather on the relationship between two equations, all of your points will fall on a perfectly smooth curve.

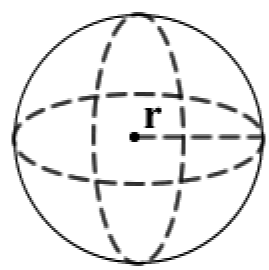
It is helpful to think about the relationship between the surface area and volume of a cube as a ratio, which we'll abbreviate as ***SVR***, which can be expressed, as follows:

$$SVR\ (surface\ area\ to\ volume\ ratio) = \frac{surface\ area}{volume} = \frac{6s^2}{s^3} = \frac{6}{s}$$

- Add a new column to your chart showing SVR.
- Then plot the relationship between ***SVR*** and cube size (side length, ***s***) placing SVR on the y-axis, and ***s*** on the x-axis in this new graph.
- Check your work in the answer sheet under **Q3**.
- Inspect your new graph to answer **Q4**.

Q4. How does surface area to volume ratio (***SVR***) of the cube change as the cube increases in size?

Since many cells are spherical in shape, let's examine the relationship between the surface area and volume of a sphere.



Now imagine a sphere with radius ***r***. The equation for finding the surface area of a sphere is as follows:

$$Surface\ area\ of\ a\ sphere = 4\pi r$$

where π (pi, pronounced like "pie") is a constant that is approximately equal to 3.14. The equation for finding the volume of a sphere is as follows:

$$Volume\ of\ a\ sphere = \frac{4\pi r^3}{3}$$

- Complete a table similar to that constructed in for the cube, calculating the surface areas and volumes of spheres with radii from 1-10 units. Check your results under **Q5** in the answer section of this book.

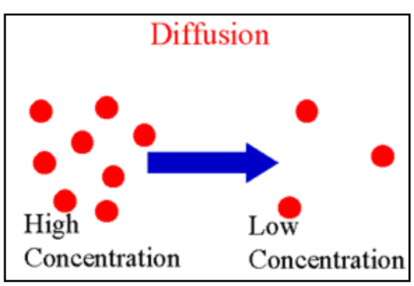
- Next, plot these data, with the surface area of the sphere on the x-axis, and the volume of the sphere on the y-axis. See **Q6** in the answer section to check your results.
- Finally plot/graph the relationship between ***SVR*** and sphere size (radius, ***r***) by plotting ***SVR*** on the y-axis, and ***r*** on the x-axis in a new plot. See **Q7** in the answer section to check your work.

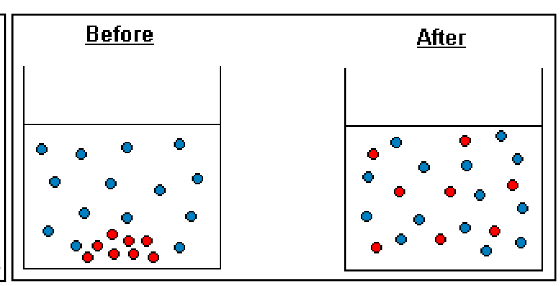
It is time to compare the graphs that you constructed for the cube (in **Q2** and **Q3**) to those that you just constructed for the sphere (in **Q6** and **Q7**).

Q8. In what ways are the two sets of graphs similar and in what ways do they differ?

Q9. From these plots, what general statement can you make about the relationship between surface area and the volume of shapes as they increase in size?

Some reflection about how surface area and volume limit cell size will get you on the right track to understanding why there aren't any car-smashing bugs around, nor is there any evidence of them in the fossil record! The volume of a cell increases at a greater rate than the surface of that same cell as cell radius (equal to ½ the diameter of the spherically shaped cell) increases. As the cell increases in diameter, the gas exchange (oxygen in and carbon dioxide out) needed for cell function decreases to a point where the cell cannot survive. Remember, a cell has no mechanism of forcefully moving gases into and out of it. Rather, gas exchange in cells occurs through simple diffusion, defined as the movement of molecules from areas of high concentration to areas of lower concentration. Diffusion continues until the molecules are evenly dispersed. The process of diffusion and its outcome are shown in the two following figures.





- Your team and class should discuss the following question before moving on.

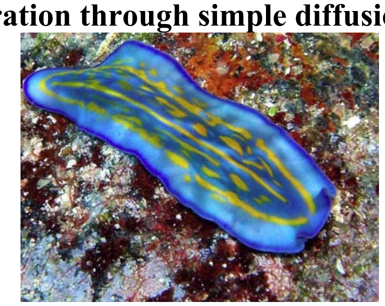
Q10. Aside from developing some form of active pump, what can a cell do to overcome the problem of decreasing rate of gas exchange with increasing size? Check in the answer section to see what solutions to this problem cells exhibit.

How many multicellular organisms face the same problem that cells have as they increase in size? A number of different phyla, in fact! All animals need oxygen for respiration, and release carbon dioxide as a waste gas.

- Tackle the following two questions:
- Sort through the organisms in your box, and find those that complete gas exchange through simple diffusion across a body surface. You might need to read the descriptions of the organisms and/or do some internet research to accomplish this task. One of the answers to **Q10** will also be helpful in completing this endeavor.
- Consider the problem terrestrial (land dwelling) insects such as the praying mantis or ant seen in horror flicks have. Why are they unable to exchange gas across their body surfaces?
- After you have come up with answers to these two questions, you can check your answers under **Q11** and **Q12** in the answer section at the end of the book before moving on to the next section.

Primitive (early) multicellular animals, such as the flatworms like the one pictured below, may accomplish gas exchange between the cells and the surface of the body. They can do this because they have paper-thin bodies that are just a few cell layers thick. Their gas exchange needs are also low, as they are typically slow-moving scavengers or exist as parasites, living off other organisms.

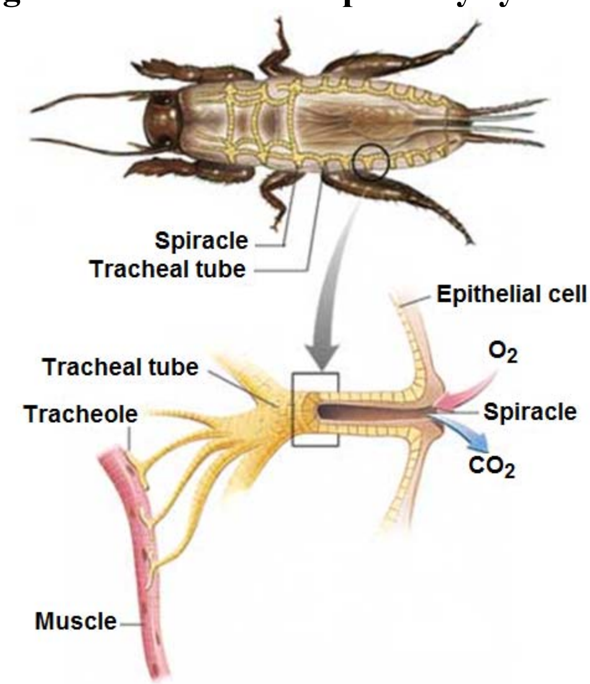
A colorful marine flatworm, displaying the thin body plan associated with flatworm respiration through simple diffusion through the body surface. Photo credit: Ken Knezick.



However, insects, as terrestrial animals, are concerned with the loss of water across the body surface. An impermeable waxy cuticle is an adaptation to terrestrial habitats. While this waxy layer prevents water loss, it also prevents gas exchange.

Insects, unlike humans and other terrestrial vertebrates, lack lungs. Instead, gas exchange is largely a passive one, accomplished through a network of tubes called **tracheae**, pronounced 'TRAY-key-eye'; singular = **trachea**, pronounced 'TRAY-key-uh'. These tubes collect air at the surface of the insect through openings called **spiracles** (pronounced 'SPEAR-uh-kullz'). From there, molecules of oxygen flow from the region of high concentration near the spiracle into regions of low concentration at individual cells or small clusters of cells. Carbon dioxide flows in opposite directions through the tube system. In many insects, this gas exchange happens only by simple **diffusion**. More advanced insects are able to regulate this flow somewhat, through muscular contractions of the abdomen, and by relaxing and contracting the spiracles. See the figures below for an illustration of a generalized insect respiratory system and an electron micrograph of a real tracheal tube.

A generalized insect respiratory system.

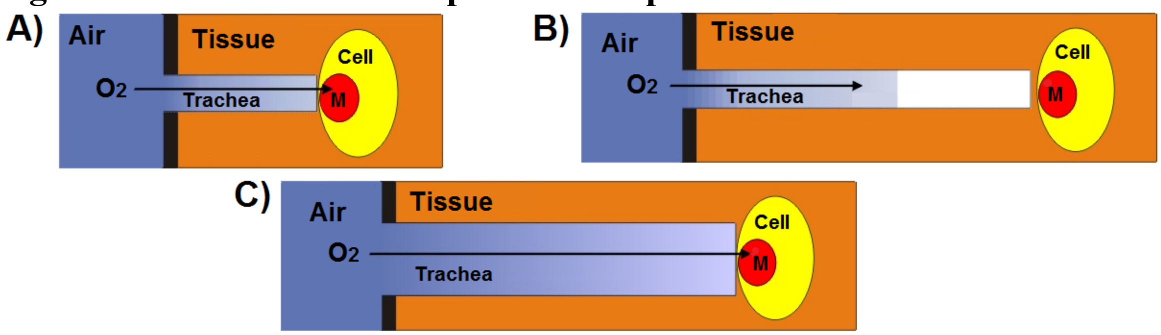


Electron micrograph of a tracheal tube

- Imagine that you are in a horror flick, tied up and buried in a box underground.

- Find the straw and the large diameter tube provided in your box. Which one of these would you want be your access to air above ground? Why?
- Now extend this question to insects, who exchange gases through tracheal tubes. If you were an insect, how big would your trachea need to be? If you think back to the importance of surface area and volume, you might conclude (correctly) that this would depend on your size. Why? Figure 3 below provides an example, using simplified diagrams representing both small and large insects.

Figure 3. Illustration of the problem of spiracle size relative to insect size.



- Examine Figure 3. Figure 3A represents a small insect, with a small diameter spiracle and trachea. In this case, oxygen (O_2) can reach the cells in the tissue fairly easily, where it is utilized in the mitochondria (a single mitochondrion is labeled as "M" in each cell) in several reactions important for respiration. However, in a larger insect, with a spiracle and trachea of the same diameter (Figure 3B), oxygen levels are depleted substantially by the time they reach the cells, as it simply cannot diffuse (or be drawn) into the spiracles at a high enough rate. Figure 3C shows how larger insects deal with this problem, with spiracles and tracheae of larger diameter. In this case, the larger volume of the trachea accommodates the larger insect's need for more oxygen, since there are more cells, in a larger amount of tissue, that need this important gas.

Q13. Based on the illustration and the information above, what is a general statement that can be made about the relationship between insect body size and tracheal volume (relative to total body volume)?

Below is a table of data containing measurements of two properties relevant to **Q13** above for beetles (insect Order Coleoptera): length in millimeters and proportion of the body volume taken up by tracheal tubes.

Beetle length (mm)	**Relative tracheal volume (as % of total body volume)**
17	1.9
18	2.1
27	3.3
47	5.7
60	7.4
62	7.6
80	9.9
129	15.8

- Make a graph of the data above, plotting beetle length on the x-axis, and relative tracheal volume on the y-axis. Draw an approximate line of best fit that passes as closely to each of your data points as possible. Check your graph against the one shown under **Q14** in the answer section of this book.

Q15. Which of the following equations describes the shape of your graph of the proportion of the body taken up by tracheal tubes versus beetle length? What do the plots of the other equations look like?

A) $x^2 + y^2 = r^2$
B) $y = mx + b$
C) $y = \log(x)$
D) $y = 1/x$

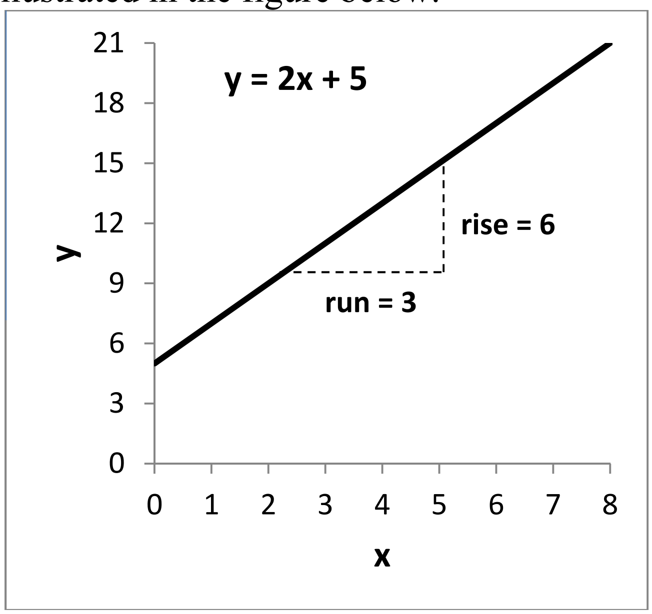
You might start by making a rough drawing of the graph each of these equations prescribes to see which one matches your data the best. **Check your answers to this question before moving on!**

A linear function is a function of the form $\boldsymbol{y = mx + b}$. Where $\boldsymbol{m}$ and $\boldsymbol{b}$ are real numbers. The number $\boldsymbol{m}$ is called the slope of the line. The number $\boldsymbol{b}$ is called the y-intercept of the line. The graph of a linear function is a line. We say that a point $(\boldsymbol{x_1}, \boldsymbol{y_1})$ is on the line if $\boldsymbol{mx_1 + b = y_1}$.

The slope $\boldsymbol{m}$ tells us how the value of $\boldsymbol{y}$ changes with the value of $\boldsymbol{x}$. The slope is equal to the change in $\boldsymbol{y}$ divided by the change in $\boldsymbol{x}$, that is, the rise over the run.

$$\mathbf{m} = \frac{\mathbf{rise}}{\mathbf{run}}$$

This definition is illustrated in the figure below.



If $(\boldsymbol{x_1}, \boldsymbol{y_1})$ and $(\boldsymbol{x_2}, \boldsymbol{y_2})$ are any two points on the line then the slope of the line is:

$$\boldsymbol{m} = \frac{\boldsymbol{y_2 - y_1}}{\boldsymbol{x_2 - x_1}}$$

If $\boldsymbol{m}$ is positive, then as $\boldsymbol{x}$ **gets bigger,** so does $\boldsymbol{y}$. If $\boldsymbol{m}$ is negative, then as $\boldsymbol{x}$ gets bigger**,** $\boldsymbol{y}$ gets smaller.

Because the slope is the quotient of the change in $\boldsymbol{y}$ divided by the change in $\boldsymbol{x}$, it is measured in $\frac{\textbf{y units}}{\textbf{x units}}$. For example, if the y-axis of a plot is measured in miles and the x-axis of the plot is measured in minutes, then the slope of a line on the plot is measured in $\frac{\mathbf{miles}}{\mathbf{min}}$.

The y-intercept $\boldsymbol{b}$ is the value that $\boldsymbol{y}$ takes when x is zero. This means that the point $(\mathbf{0}, \boldsymbol{b})$ is on the line.

- Try calculating the slope of the line representing the relationship between relative tracheal volume and beetle length. For simplicity, assume that the y-intercept of this line is at 0, since a non-existent beetle would have no tracheae. Check you answer under **Q16**.

Q17. Based on these data, what is the *theoretical* maximum size of a beetle? Hint: What if a beetle's body volume consisted of nothing but tracheae?

- Given that the largest beetle alive today (*Titanus giganteus*, a South American long-horned beetle in the family Cerambycidae, pictured below), is approximately 170mm in length, use your answer to the previous question to calculate the approximate percentage of that species' body volume occupied by tracheae. Check your answer under **Q18** in the answer section.

Q19. What do you think limits the body volume that an insect can devote to the tracheal system?

Different groups of insects may have different relationships between body length and relative tracheal volume (the best-fit lines may have different slopes).

- Using the information gained from examining the data set for beetles, answer the following questions:

Q20. If you assume that the maximum relative tracheal volume in insects as a whole is equal to the value that you calculated in **Q17**, and the relationship between length and relative tracheal volume has a slope of 0.056, what is the maximum length of this type of insect? What does this insect look like? Explain your answer!

Q21. During the Carboniferous Period (350 million years ago), there were insects much larger than any found on earth today. Develop a hypothesis to explain this observation. How would you test this hypothesis? Check your answer under **Q21** in the answer section for this exercise.

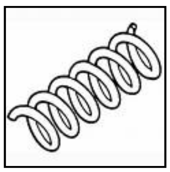
This exercise was initially developed at a National Academies Summer Institute by *Biology in a Box* Director Dr. Susan Riechert and the following additional members of a Biology/Math Interface Team: University of Tennessee colleagues Drs. Randy Brewton & Stan Guffey, Drs. Ken Brown & Hartmut Doebel from George Washington University, and Drs. Robert Malchow and Michael Mueller from the University of Illinois at Chicago.

Exercise 9: Follow that spiral!

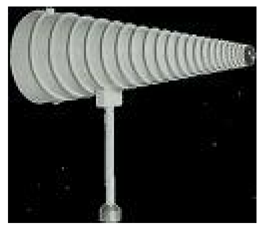
Gastropods (snails and their relatives) have only one shell*, and it is spiral in form. However, there are many other examples of spirals that can be seen in nature, as well as in objects we see or use in our everyday lives.

Q1. Examine the examples of spirals pictured below. How many of these can you identify?


A


B

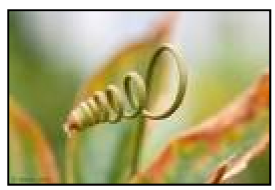

C

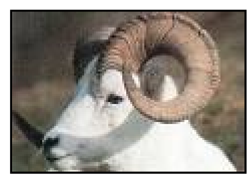

D


E


F


G


H

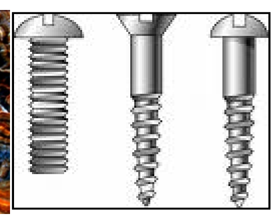

I

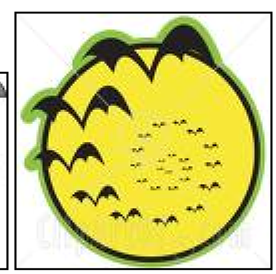

J


K


L


M


N


O

Q2. Although we can look at something and recognize it as having a spiral, can you describe a spiral in words?

Check your answers in the answer section of this book before moving on!

*** Exceptions include shell-less gastropods, such as slugs & nudibranchs (sea slugs).**

Q3. Does a snail shell have symmetry?

Q4. What purposes do you think this spiral structure might serve for a snail?

Exercise 9a: Is that snail left- or right-handed?

Are you left-handed or right-handed? Although they don't have hands, interestingly, snails also have a form of "handedness," based on the direction of the opening of their shell. How can you tell if the spiral of a snail is left-handed or right-handed? One easy way to do this is to hold the shell so that the opening is towards you, and the apex (top of the spiral) is pointing upwards. If the opening is pointed towards your left, your snail has a left-handed spiral. If the opening is pointed towards your right, your snail has a right-handed spiral. Another way is to hold the shell in the same position, and place a finger in the groove of the spiral at the apex. Trace this groove with your finger so that you are moving along the spiral path towards the opening in the shell. If your finger moves in a clockwise path along the groove, your snail has a right-handed spiral. If the path your finger traveled was counterclockwise, the spiral of the shell is left-handed. Examine Figure 1 below for an illustration of shells with left-handed and right-handed spirals.

Figure 1. "Handedness" in snail shells. The shell on the left displays a left-handed spiral, while the shell on the right displays a right-handed spiral.

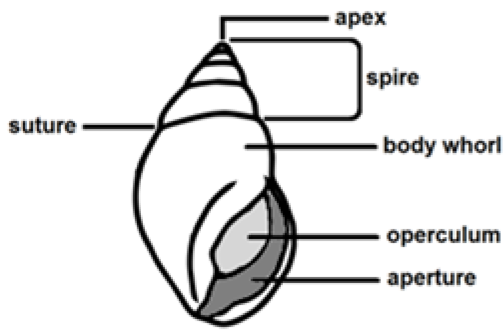
- Examine the snail shells present in your box.
- For each one, determine whether it is left-handed or right-handed, as described above.
- Sort your sample of shells into separate "left-handed" and "right-handed" piles.

Open-ended exploration: Why do you think snails might exhibit handedness? Is one particular handedness more common than the other? If so, why might this be the case? Are there any factors that may influence handedness in a particular type of snail? If so, what are they? Do some library and/or internet research on the subject, and prepare a brief presentation to share with the rest of the class.

Exercise 9b: Measure that shell!

Exercise 9b.1: Quantifying shell dimensions

Figure 2. Illustration of basic snail shell morphology.



As a snail grows, it makes its shell "house" bigger to hold its larger body. The smallest inner coil of the shell is called the **apex.** It is what remains of the original shell that the snail formed before it even hatched. Notice the spiral groove on the snail's shell. If you place your finger in the groove at the shell's apex, and follow its path, you will see that the shell gets bigger and wider as you move along the groove. This reflects the way the snail made it shell larger and larger by adding new material as it grew.

Aside from whether they are left- or right-handed, snail shells are also differentiated by their shape and size. Look at the shells in your sample and notice their many different forms. Biologists that study shells measure their features so that they can be **quantified,** or described with numbers. Today you will play the role of a **conchologist** (pronounced con-KAH-luh-gist), or scientist that studies shells. You will measure the shells in your sample so that you can quantify their features.

Examine your sample of snail shells. You may notice lots of variation amongst these shells, in terms of size, color, texture, etc., but what about shape? Can you divide your sample of shells into several groups according to their general shape?

- Separate the collection of shells into several piles, by placing shells that share similar shapes together. Try to come up with a name to describe each shape group.

- After you have grouped the shells according to shape, examine the shells within each shape group to see how they vary in size. Position the shells within each shape group according to their apparent size from smallest to largest.
- After you have ordered the shells in each shape group according to apparent size, measure each shell's size. There is more than one way to measure a shell's size. Choose one of the possible measures of shell size listed below, and measure this value for each shell.
- Make a table in which to record each shell's apparent size ranking (1 being the smallest), and its size measurement. See the table below for an example.

Rank	**Size measurement (number of whorls)**
1	1.25
2	2.75
3	3
4	3.5

Q5. Does your ranking according to apparent size agree with your size measurements? Why might your visual rankings differ than rankings based on your measurements?

<u>Size measurements for students of all ages:</u>

- o **Number of whorls:** This is the number of full rotations of the spiral path of the shell as you move from the apex to the opening. To calculate the number of whorls place your finger on the spiral groove at the apex of the shell and trace its path. Count how many full circles you make as you follow the path to the shell's opening. Estimate partial rotations as you near the opening as fractions of a full rotation (for example, 0.25, 0.5, etc.).
- o **Width and/or height of the aperture (opening)**
- o **Shell height:** Hold the shell so that the opening is facing you, and the apex is facing upwards. The height of the shell is the straight-line distance from the very bottom to the top of the shell when held in this position.
- o **Shell width:** With the shell held in the same position as above, measure the greatest straight line distance across the shell.
- o **Greatest shell circumference:** Wrap a piece of string around the widest part of the shell, then straighten out the string and measure the part that wrapped all the way around the shell at this point.

- An alternative of measuring height, width, or circumference of the shells could be accomplished via tracing each of the shells on a piece of paper, and taking the measurements from the traced outlines. Though this will introduce some error due to the width of the instrument used to trace each shell, since this will be the same for each shell, this would still be an effective way of obtaining ranked size measures of each shell.

Circumference of each shell could then be calculated from the drawings, since the greatest width of each outline would correspond to the diameter of the shell, and the known relationship ($\boldsymbol{C = \pi d}$) between circumference and diameter.

Size measurements for grades 3 and up:

- **Shell volume:** If you measure the shell circumference and its height, you can estimate the volume of the shell by using the equations for the volume of a cone (for pointier shells), a cylinder (for more flattened shells), or a sphere (for rounder shells). These formulas are listed below.

$$\boldsymbol{Volume\ of\ a\ cone = \frac{1}{3}\pi r^2 h}$$
$$\boldsymbol{Volume\ of\ a\ cylinder = \pi r^2 h}$$
$$\boldsymbol{Volume\ of\ a\ sphere = \frac{4}{3}\pi r^3}$$

  In these equations, $\boldsymbol{h}$ represents the shell height, $\boldsymbol{\pi}$ ("pi") is a constant that is approximately equal to 3.14, and $\boldsymbol{r}$ is the radius of a circle. In the formula for the cone $\boldsymbol{r}$ represents the radius of the circle that forms the base of the cone. In the formula for the cylinder $\boldsymbol{r}$ represents the radius of the circle that forms the base of the cylinder. In the formula for the sphere $\boldsymbol{r}$ represents the radius of the equator of the sphere. You can calculate the radius from your value of shell circumference.
- **Area of the aperture:** You can estimate this area by using the formulas listed below. Use the formula for the shape that is the most like the opening to your shell.

$$\boldsymbol{Area\ of\ a\ circle = \ \pi r^2}$$
$$\boldsymbol{Area\ of\ an\ ellipse = \frac{1}{2}\pi ab}$$

- In the formula for the area of a circle, $\boldsymbol{r}$ represents the radius of the circle. In the formula for the area of an ellipse, $\boldsymbol{a}$ and $\boldsymbol{b}$ represent the width and height of the ellipse respectively.

Q6. The equation for the circumference of a circle with radius $\boldsymbol{r}$ is $\boldsymbol{C = 2\pi r}$. Rearrange this equation to solve for $\boldsymbol{r}$ in terms of $\boldsymbol{C}$.

Q7. How is a snail's shell volume related to its body size?

- We can also compare shells to see how much bigger one shell is than another shell. In particular, we can find the **factor** by which one shell's size is greater or less than another shell's size. The factor by which one number is greater or less than a second number is the number that we have to multiply the second number by to get the first number back. For example, the value of a dime is greater than the value of a nickel by a factor of 2, because we have to multiply the value of a nickel by 2 to get back the value of a dime.

Factors

If y is greater or less than x by a factor of c, then $y = cx$.

If we divide both sides of this equation by x we find that $\frac{y}{x} = c$.

In other words, the factor by which y is greater/less than x is equal to $\frac{y}{x}$.

Q8. What is the factor by which the value of a nickel is less than the value of a dime?

Q9. What is the factor by which the value of a nickel is less than the value of a quarter?

Q10. What is the factor by which the value of a quarter is greater than the value of a nickel?

Q11. Complete the following sentence: If x is greater than y by a factor of $, c$ then y is less than x by a factor of ___.

- Suppose that we ranked a sample of five shells according to their whorl numbers and then organized this data in a table like the one pictured below.

Whorl number	The factor by which the whorl number increases (relative to next smaller shell)
1	
2	
2.5	
3.25	
3.5	

- To complete the table we need to find the factor by which the whorl number increases from one shell to the next. For example, to find the factor by which the whorl number increases between shell #1 and shell #2, we divide the number of whorls that shell #2 has by the number of whorls that shell #1 has.

$$\frac{\#\ of\ whorls\ on\ shell\ \#2}{\#\ of\ whorls\ on\ shell\ \#1} = \frac{2}{1} = 2$$

That is, shell #2 is twice as many whorls as shell #1. Similarly, we can find the factor by which the number of whorls increases between shell #2 and shell #3.

$$\frac{\#\ of\ whorls\ on\ shell\ \#3}{\#\ of\ whorls\ on\ shell\ \#2} = \frac{2.5}{2} = 1.25$$

That is, shell #3 has 1.25 times as many whorls as shell #2.

Whorl number	**The factor by which the whorl number increases (relative to next smaller shell)**
1	Can't be calculated
2	2
2.5	1.25
3.25	
3.5	

- Complete the table above, and then construct a similar table for each of your shell shape groups to show the factor by which the size measurement that you chose increased from one shell to the next.

Exercise 9b.2: Making Connections

Examine the shells in each shape group. What can you learn about a snail's lifestyle (i.e. where it lives, what it eats, how fast it moves, how it defends itself against predators, etc.) by examining the shape of its shell? Does the shape of a snail's shell serve a function, help the snail to accomplish particular tasks, or is the shape of the shell the result of the environment in which the snail lives? Do other shell traits, besides shape, give you insight into a snail's life?

- Pick a particular aspect of a snail's lifestyle that interests you.
- Think of a few (at least 2-3) traits that might be related to the lifestyle aspect that you chose. The following page lists of a few examples of additional traits that you could measure, in addition to the size-related traits from earlier. You may also measure any other traits that you think might be important.

- Measure these traits for each of your shells, and record this data in tables for each shape group, similar to the one below. Use mm for linear measurements.

Shell #	Trait #1	Trait #2	Trait #3

Below are some other shell traits you can measure. If necessary, ask your teacher for help making these measurements. Look back at Figure 2 if you need any help with terminology regarding parts of the shell. You are welcome to measure any other traits related to shell shape that may interest you. Just be sure to clearly define how you make such a measurement, and be consistent in the methods of your measurements from shell to shell.

<u>**Other measurements:**</u>

- **Color variation:** Some shells are a solid color, while others are variegated. A possible quantitative measure of the variation in shell color would be to count the number of colors on the shell.
- **Relative height:** This is simply the height of the shell divided by its width. This number could actually tell someone about the shape of a shell without them even seeing it! Large values of this ratio indicate that a shell is long and thin, while small values of this ratio indicate that a shell is short and flat.
- **Whorl expansion rate:** This is the factor by which the diameter of the aperture increases with a single rotation. It may be difficult to measure the whorl expansion rate if your shell is intact and the whorls overlap. However, there are many ways to estimate this rate. For example, you could estimate the whorl expansion rate by dividing the height of the visible part of a particular whorl by the height of the visible part of the whorl formed before it (closer to the apex).
- **Shell angle:** This measurement also gives some information about the shape of a shell, and can be measured as the angle formed by the apex of the shell and the most external sutures on the shell.

For an illustration of these measurements, as well as many other informative measures of shell shape, the following link provides images, as well as descriptions on how to measure these traits:

<u>http://en.wikipedia.org/wiki/File:Gastropod_shell_measuring.png</u>

Looking for correlations:

- After you have recorded your data, look to see if the traits you measured are correlated. If one trait is usually large when another trait is large, then there is a positive correlation between the traits. If one trait is usually small when another trait is large, then there is a negative correlation between the traits. You may wish to create graphs or plots to better visualize and evaluate whether such relationships are present.
- If relationships exist between traits, are these relationships similar or consistent among different shape groups? Why do you think this may or may not be the case?

Further open-ended exploration:

- Using the shell identification guide in the answer section of this book, find the species of snail that made each shell in your collection, and add this information in a new column in your tables.
- Use the library or the internet to research these snail species. As you research each snail species, try to answer the following questions:
    - Do the shell traits that you measured seem to be related to the lifestyle aspect that you chose to study?
    - If so, why might these traits be important?
    - How do they relate to your chosen aspect of snail lifestyle?
    - If not, can you find other aspects of the snails' lifestyles that appear to be related to the traits you chose to measure?
- Prepare a brief report of your findings to present to the rest of your class.
- **NOTE:** Teachers may wish to provide a scientific review article on the importance of various aspects of land snail shell shape (included with the teacher materials for Unit 6 on the *Biology in a Box* CD) to more advanced students to assist them. However, students should consider the following:
    - The provided article is primarily concerned with land snail species, while some of the provided shells come from aquatic species.
    - Do you think that shell shape traits may differ in importance between land and aquatic snails? If so, how?
    - What about different types of aquatic habitats (for example, freshwater versus marine dwelling snails)?

An optional web-based exercise:

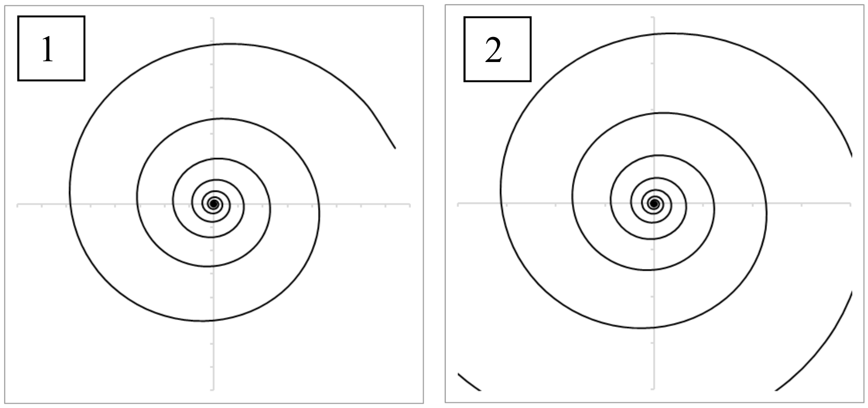
- Go to *http://www.ams.org/featurecolumn/archive/shell6.html*, and play around with some of the parameters (***W***, ***D***, and ***T***), clicking the "*Draw*" button to see their effects.
    - Can you think of ways to measure your snail shells so that you can estimate these parameters?
    - Try to see if you can do so for one or more of your shells. If you think you have come up with a way to estimate ***W***, ***D***, and ***T*** for those shells, try using those parameters in the model.
    - Can you produce a shape similar to that of any of the shells in your sample?

Exercise 9c: That Mathematical Mollusk: The Nautilus

In Exercises 9a and 9b, we examined snails (gastropods) that all have spiraled shells associated with a twisting of the digestive tract and organs called torsion. The shell of a cephalopod called the nautilus also reflects a spiral growth pattern. This is the only living cephalopod (squids and octopi) that has a shell. The nautilus displays a growth pattern that approximates a special kind of spiral, known as a **logarithmic spiral**.

The logarithmic spiral exhibits **scale symmetry**. In contrast to the types of symmetry that you explored earlier in this unit, scale symmetry refers to repeated structures that look the same at differing levels of magnification. For example, Figure 3 shows a logarithmic spiral in two views. The second view shows the spiral seen in the 1st view magnified by a factor of 2. As you can see, the image in 1 is included in image 2; the spiral merely has an additional larger whorl added. The reason that nautilus shells only approximate logarithmic spirals is that this animals' shell winds around its center a finite number of times as it grows to its maximum size, while logarithmic spirals wind around their centers infinitely many times.

Figure 3: The logarithmic spiral exhibits scale symmetry. The picture on the right is a magnification of the one on the left by a power of 2.



- Find the nautilus shell cut along its midsagittal plane to expose its inner chambers.
- Examine the central portion of the spiral. These are the chambers of the nautilus's shell that were formed first, when the animal was still small. As the nautilus grows, it adds new chambers to its shell, and moves its body into the larger, most recently formed chamber, sealing off the last, smaller chamber behind it with a wall called a **septum** (plural = **septa**). You may notice on some of the septa, however, a small hole or remnants of a tube-like structure. These represent the remains of the **siphuncle**, a strand of tissue that passed through each of the shell's chambers when the organism was alive. The siphuncle essentially functions to move water and gases in and out of the otherwise sealed chambers. Though this happens relatively slowly (by passive diffusion), as the nautilus physiologically adjusts the saltiness of its blood in the siphuncle, this allows the nautilus to change the density (and thus buoyancy) of its shell. This assists it in maintaining an upright position in the water column.
- Note that the shapes of the chambers, each of which contained the living animal at a particular point in its life, are all quite similar. An interesting property of the approximately logarithmic spiral growth pattern in the nautilus is that this pattern allows the nautilus to grow at a constant rate, without having to change shape or proportions of its body parts as it grows (this is known as **isometric growth**; the prefix *iso*- means "equal", and *metric* means "measure"). Organisms which change shape or proportions as they grow are said to exhibit **allometric growth.** Humans represent a good example of allometric growth, as babies' heads are much larger in proportion to the rest of their bodies when compared with adults.

Snails too exhibit a form of logarithmic spiraling, but there are no growth compartments, and the spiral in the snail is "stretched out" along an axis in three dimensions. These special types of stretched out logarithmic spirals are called logarithmic **helicospirals**, as they are a combination of a helix and a spiral.

In this exercise, you will learn a little more about the properties of logarithmic spirals, as well as how this information relates to growth patterns observed in the nautilus.

Exercise 9c1.1: Build that Nautilus! (Grades 2-12)

Materials

- Photocopy of template with 12 triangles
- Scissors
- Blank paper (optional)
- Glue or tape (optional)
- Protractor (for older students)

Your teacher will provide you with a copy of a template containing several triangles (found on page 60).

- Feel free to color in and decorate the triangles as you wish.

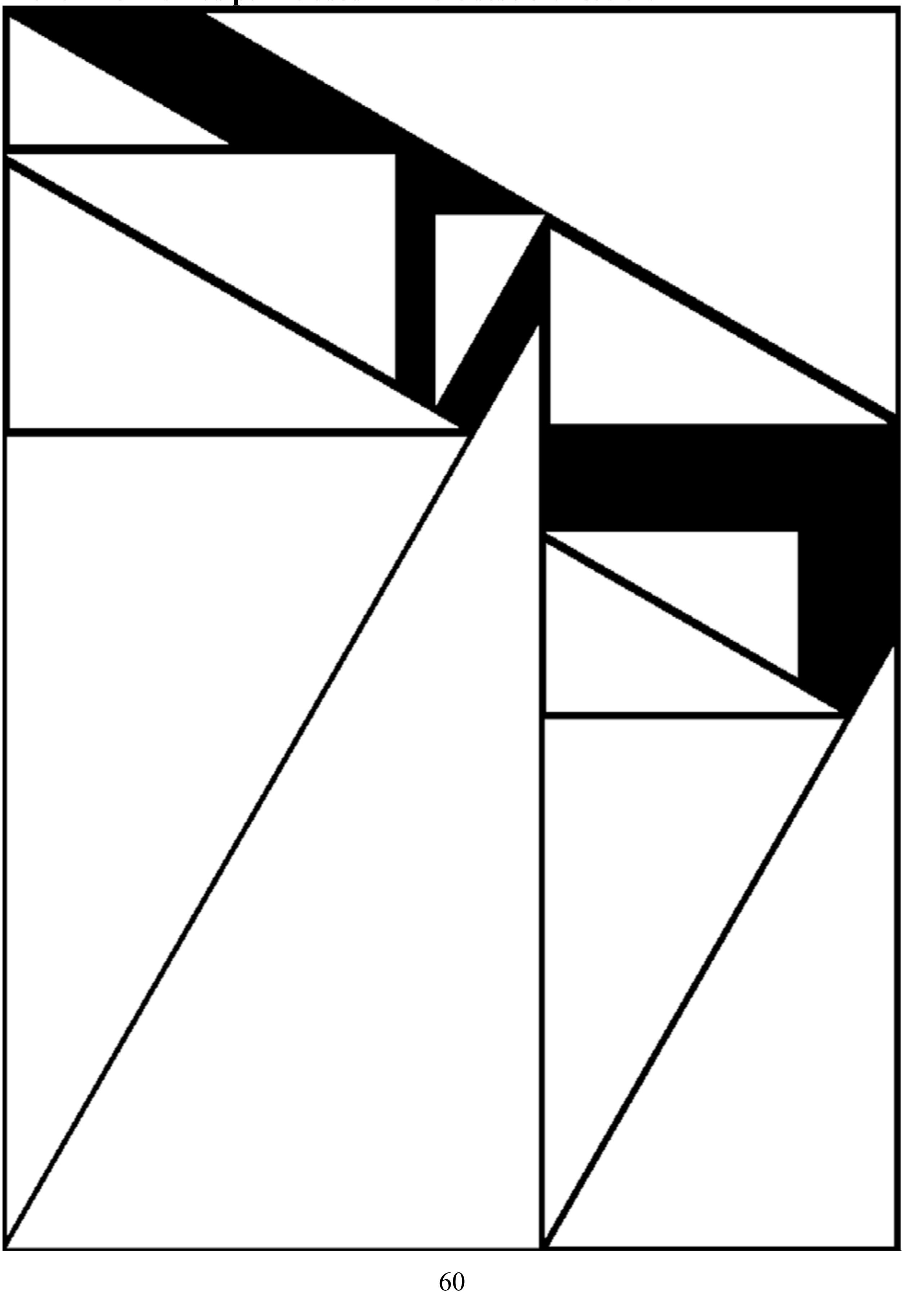
There is a special relationship amongst these triangles in terms of scale (size).

- Cut out the triangles, and see if you can get them to fit together in such a way that a given side of a triangle is aligned with a different side (which should be the same length) of the next larger triangle.
- Tape or glue these pieces onto a blank sheet of paper to keep, or your teacher may wish to display these in the classroom.

Q12. What sort of shape does the completed puzzle form? Compare the completed puzzle to the nautilus shell in your box. Are they similar?

Additional background information for teachers (and students, once they have completed this exercise), can be found in the answers section at the end of this book.

Template for the nautilus puzzle used in Exercises 9c1.1 & 9c1.2

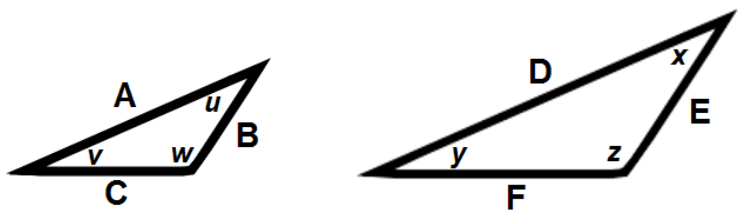


Exercise 9c1.2: Are those Triangles Similar? (Grades 5-12)

Similar triangles are triangles that have exactly the same shape, but differ in size. You may think that all triangles are the same shape, because they all have three sides, but in mathematical terms, to say that triangles have the same shape (are similar), they have the following properties in common, which are also illustrated in Figure 4:

1. Corresponding angles of similar triangles have the same measurement.
2. The ratios of corresponding sides of similar triangles are all the same.

Figure 4. Properties of similar triangles.



<u>**Properties of similar triangles**</u>

$\angle u = \angle x$
$\angle v = \angle y$
$\angle w = \angle z$

$$\frac{A}{D} = \frac{B}{E} = \frac{C}{F}$$

- Using the provided protractor, measure the angles on each of the triangles in your nautilus puzzle, recording them in a table similar to the one below:
- Pick a particular side of one of the nautilus puzzle triangles (for example, the side opposite the smallest, medium, or largest angle. Measure your chosen side (in millimeters) using one of the provided rulers. Record this data in the "*Chosen side*" column of your table, as well.

Triangle #	Smallest angle	Medium angle	Largest angle	Chosen side	Relative to corresponding side on next smallest triangle
1 (smallest)					*Not applicable*
⋮					
12 (largest)					

- For your chosen side on each triangle, calculate its size relative to the corresponding side of the next smallest triangle, and record this value in the last column of the table. You would simply calculate this value by dividing the "*chosen side*" length of a given triangle by the corresponding side length of the triangle in the row above it in your table.
- Compare the values of each of the angles in your triangles in your table.

- Also examine the column of the corresponding sides of each of the nautilus puzzle triangles.

Q13. Are these values similar for the smallest, medium, and largest angles in each of the nautilus puzzle triangles?

Q14. Are all of the ratios of corresponding sides between a larger triangle and the next smaller triangle close to the same value?

Q15. Based on your answers to the previous questions, would you say that the triangles are all similar triangles? How does this relate to the growth observed in the nautilus?

- Make a plot of triangle size (either using your chosen side, or of triangle area, calculated from the formula Area = ½ × base × height) versus triangle number (using 1 to represent the smallest triangle, and 12 to represent the largest triangle).

Q16. What is the shape of this plot? Does the relationship between triangle size and triangle number appear to be linear?

Simpler exercise on similar shapes for grades 2-4:

- Using 1-cm grid paper and a straightedge or ruler, draw a simple shape that has only straight lines and with all vertices (corners) only at points where the graph paper's vertical and horizontal lines intersect (cross each other) on the paper.
- Label each of your vertices with a letter.
- Once you have completed this first shape, use a piece of 2-cm grid paper and draw the same shape using the same number of squares you used in the first drawing to determine where you will begin and end your lines. Label the vertices of this shape with the same letters as those you used on the first shape, making sure that points with the same letters correspond between your two shapes.
- Choose two sides of your first shape and measure their length, or count how many grid squares their length represents.
- Form a ratio of those two side lengths using one of the lengths as your numerator and the other length as your denominator.

- Find the sides of the second shape that correspond to the sides you measured in your first shape.
- Measure those side lengths, or count the number of grid squares their lengths represent.
- Form a ratio of those two lengths being sure your two numerators represent corresponding sides and your two denominators represent corresponding sides.
- Try to answer the following questions:
    - How do your ratios compare? If you do not see a relationship right away, use a calculator and divide the numerator of each ratio by its denominator. (Or, you can simplify the ratios if the numbers are easy to work with.)
    - How do the quotients compare?
    - What do you think that number is telling you?

Similar shapes will have the same ratio of corresponding sides, or the ratio of two sides of one shape will be the same as the ratio of corresponding sides in a second similar shape. The quotients of the two ratios should be the same number.

Exercise 9c.2: Parameterize that spiral! (For high school students that have had trigonometry)

Materials

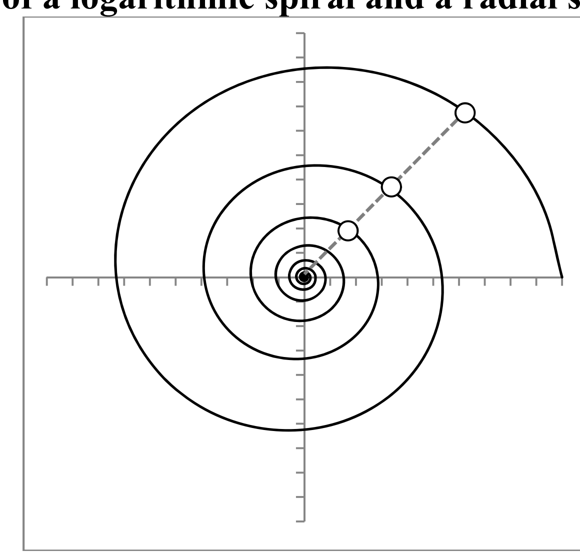
- nautilus shell in sealed container, with polar coordinate gridlines drawn on it
- ruler
- rubber bands
- protractor
- scientific calculator (or the Excel spreadsheet provided on the teacher CD)

The scale symmetry of the logarithmic spiral endows it with many distinctive features.

- Picture a spiral centered at the origin of the Cartesian coordinate plane, as seen in Figure 2 below. Now imagine that you are walking along a radial spoke, outward from the spiral's center (the origin). As you progress along this spoke, the distance between the origin and each successive point on the spiral intersected by this radial spoke (representing 2π rotations around the origin) increases by a constant factor.

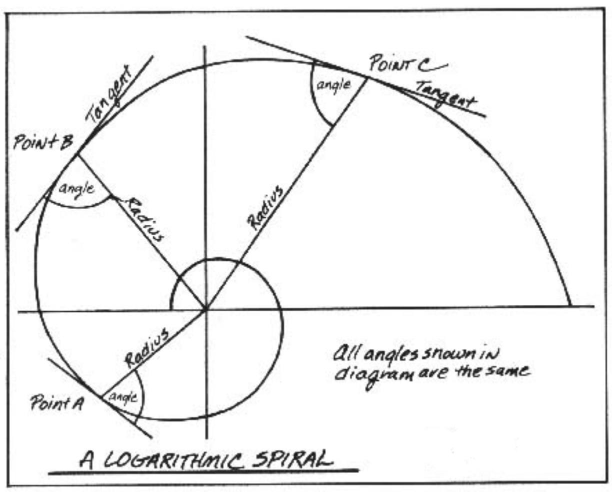
As you might guess by looking at Figure 2, there is nothing special about this particular radial spoke. If you had chosen to walk along any other radial spoke, the same thing would happen: the distances between the successive points of intersection and the origin would increase by the constant factor ***k***. Later on in this exercise, you will collect actual data from your nautilus shell, and use this to estimate a value of ***k*** for your shell.

Figure 2: Intersections of a logarithmic spiral and a radial spoke.



Another interesting aspect of logarithmic spirals is based on the properties of angles formed between radii drawn to points on the spiral (lines drawn from the center of the spiral to a point on the curve) and the tangents to the curve at those point (lines that just pass through those curves, and which basically show the direction that the curve is moving at that point). A unique property of logarithmic spirals is that **at any point on the spiral, the angle formed between the radius drawn to that point and the tangent to that point always remains the same.** For this reason, logarithmic spirals are also known as **equiangular spirals**. Figure 3 below is an illustration of this property of logarithmic spirals.

Figure 3. Illustration of the equiangular property of logarithmic spirals.

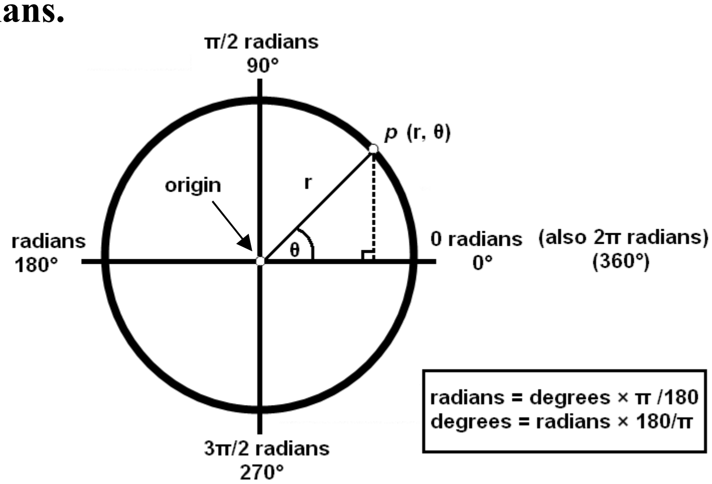


The equal angles formed by the radii at any points, and the tangents to the curve of the spiral at those points is related to the constant factor ***k***, by which distances from the origin to successive points on the spiral increase. We will return to this point a little later on, after a little more information on equations of logarithmic spirals.

Logarithmic spirals can be described in mathematical language, or in other words, by an equation. The simplest type of equation to describe a logarithmic spiral is a polar equation, using a system of polar coordinates. You are probably already familiar with the Cartesian (x,y) coordinate system, but the polar coordinate system is a bit different. First, we will give you an introduction on polar coordinates, and what they mean.

In the Cartesian coordinate system, the location of a point is described by giving a horizontal (x) distance from the vertical y-axis, and a vertical (y) distance from the horizontal x-axis, with the two axes intersecting at the origin. However, to describe the location of a point in polar coordinates, this is done using just a distance (usually denoted as ***r***) and an angle (usually denoted as ***θ***, which is the Greek letter "theta"). To get a better sense of how this is done, imagine the traditional horizontal and vertical axes of the Cartesian coordinate system, with the origin at their intersection. In polar coordinates, the distance ***r*** describes the distance of a point from the origin. However, in the polar coordinate system, if we were just given a value of ***r***, that point could be anywhere that is a distance of ***r*** from the origin. In other words, the point could fall anywhere on a circle with a radius of ***r***. If we want to describe the precise location of a point using polar coordinates, we need to specify another coordinate that would tell us exactly where that point would fall. This is where the angle ***θ*** (theta) comes in. Look at the circle in Figure 4. If you have had a geometry course, you know that a circle is made up of 360 degrees. So, if we specify an angle between 0 and 360 degrees, we would then be specifying the exact location of a point (with a given distance ***r*** from the origin) on the circle with radius **r**. In the polar coordinate system, this is done by expressing the angular position **θ** relative to the horizontal axis. In Figure 4 the marked point, ***p***, on the circle is at a position with an **θ** of approximately 45 degrees.

Figure 4. An illustration of polar coordinates, with angular measurements in degrees and radians.



However, in the polar coordinate system, angles are not expressed in terms of degrees. They are expressed in terms of another angular unit called the radian (plural = radians). This might sound a bit intimidating at first, but it's not as complicated as it sounds. Let's think of it again in terms of circles.
In a circle, the perimeter (the distance around the circle) can be expressed as a function of the circle's radius (***r***): $P = 2\pi r$ (where π, or "pi" is approximately equal to 3.14159). Imagine a point, on the circle of radius ***r***, on the positive horizontal

axis as representing an angular position of 0 radians. If we travel counterclockwise around the circle to the 45 degree point as above, we have traveled 1/8 of the way around the circle. This angular distance, expressed in radians, would be equal to $2\pi/8$ (since all the way around the circle would be equal to 2π radians, and we have only traveled one eighth of the way; we could simplify this to $\pi/4$ radians). Following this same logic, 180 degrees would be equal to $2\pi/2$ (or simplified, π) radians, since that represents traveling counterclockwise halfway around the circle. You can easily convert degrees to radians (and vice versa) by just remembering this relationship: 2π radians = 360 degrees. To convert a degree measurement to radians, use the following:

$$\boldsymbol{Angle\ in\ radians} = \frac{\mathbf{2\pi}(\boldsymbol{angle\ in\ degrees})}{\mathbf{360}\ \boldsymbol{degrees}} = \frac{\boldsymbol{\pi}(\boldsymbol{angle\ in\ degrees})}{\mathbf{180}\ \boldsymbol{degrees}}$$

It is convenient to express the equation of a logarithmic spiral in **polar coordinates**. Again, this means that a point on the spiral is determined by $\boldsymbol{r}$, its radius (or distance from the origin) and $\boldsymbol{\theta}$, its angle from the x-axis (measured in radians). Generally we consider $\boldsymbol{r}$ to be a function of $\boldsymbol{\theta}$, denoted by $\boldsymbol{r(\theta)}$.

$$\boldsymbol{r(\theta)} = \boldsymbol{the\ radius\ of\ the\ point\ on\ the\ spiral\ whose\ angle\ is\ \theta}$$

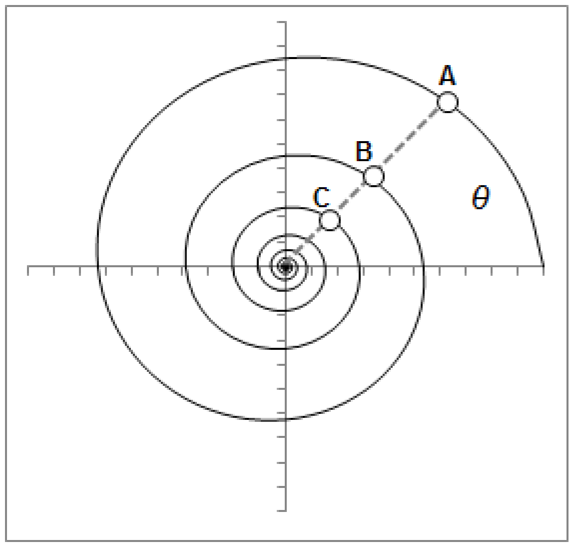
For a spiral with a counterclockwise orientation like the one in Figure 5, θ varies between 0 and ∞, that is, $0 < \theta < \infty$.

In particular, in winding one time around the origin in a counterclockwise direction, the angle increases by 2π radians.

- Examine Figure 5 and answer the following question.

Q17. What is the angle between point C and the x-axis?

Figure 5: The graph of a logarithmic spiral. A point on the spiral is determined by its angle and radius. The angle between the point A and the x-axis is $\boldsymbol{\theta}$. The length of the line connecting point A to the origin is equal to $\boldsymbol{r(\theta)}$**.** The angle between point B and the x-axis is $\theta + 2\pi$ because the spiral winds around one time in a counterclockwise direction between point A and point B. The length of the line connecting point B to the origin is $r(\theta + 2\pi)$.



Now that you have had a crash course in polar coordinates, we will present the equation (in polar coordinates) used to describe a logarithmic (equiangular) spiral. Later, we will return to this equation, and use it to see if we can figure out the equation that best describes the nautilus shell in your box. The equation for a logarithmic spiral can be given as

$$\boldsymbol{r = ce^{\theta \cot \alpha}}$$

where ***r*** is the radius from the center of the spiral to a point on the spiral, ***c*** is a constant, ***e*** is a constant representing the base of the natural logarithm (***e*** is approximately equal to 2.718), $\boldsymbol{\theta}$ is the angular measurement (in radians) that describes the location of this point, $\boldsymbol{\alpha}$ is the angle between the radius to that point and the tangent to the curve at that point, "*cot*" is the **cotangent** of the angle $\boldsymbol{\alpha}$. The cotangent of an angle is simply the **reciprocal of the tangent** of that angle. If you are not familiar with the tangent of an angle, it is a term that refers to a quantity expressing the *relationship between the lengths of the opposite and* *adjacent sides of a right triangle also containing the specified angle*. The tangent is expressed as

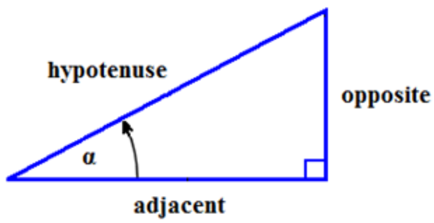
$$\tan \alpha = \frac{\textit{length of side opposite the angle}}{\textit{length of side adjacent to angle}}$$

Thus, the cotangent, since it is the reciprocal of the tangent, would represent the ratio

$$\frac{\textit{length of side adjacent to angle}}{\textit{length of side opposite the angle}}$$

Figure 6 below should help you understand a little better how "opposite" and "adjacent" sides are defined.

Figure 6. Opposite and adjacent sides to an angle in a right triangle, and definitions of several trigonometric functions.



sin α = opposite/hypotenuse

cos α = adjacent/hypotenuse

tan α = opposite/adjacent

Remember, the definition of a logarithmic (equiangular) spiral specifies that the angle α remains constant!

Now that you have had a brief crash course on logarithmic spirals and trigonometry, let's return to our real world example of where such mathematical phenomena can be observed: the nautilus. In your box, you should also be provided with a clear plastic container with half of a nautilus shell inside. The lid of the container is also marked with a grid of radial spokes, each of which is labeled with angular measurements (in radians and degrees). For the next exercises, you will use this shell, along with a few other materials, to examine the pattern of growth in the nautilus, as well as to figure out the equation that describes the logarithmic spiral approximated by your nautilus shell.

Instructions

- Divide the class into teams of 3-4 students.
- Each team should have a nautilus shell to work with and an Excel spreadsheet template.
- Starting at the center of the spiral, measure (in mm) outwards from the center of the spiral along the line corresponding to $\theta = 0$ radians (which should be the gridline joining the center of the spiral to the outermost edge of the spiral) to the point on the spiral ***nearest the center*** that this line intersects. Record this distance.
- Move along the spiral's curve from this point until you reach a point on the spiral intersected by the $\theta = \pi/4$ radians line on the grid. Record the distance between this point and the center as well. Continue along the spiral, measuring the distance between the center and each point on the spiral that intersects the next gridline (in increments of $\pi/4$ radians). Make all measurements permitted until you have reached the outermost portion of the spiral that is intersected by one of the radial gridlines.
- Enter the data that you have collected into the Excel spreadsheet provided on the teacher CD for this unit (your teacher should already have this spreadsheet open for you), entering your first measurement (from step 4) in the *"Radius (mm)"* column. Continue filling in the spreadsheet with each of your successive measurements. **NOTE: Traditionally, angles in the polar coordinate system are measured counterclockwise from the positive horizontal axis (to the right of the origin), with the positive horizontal axis representing an angle of 0 radians, and the horizontal axis to the left of the origin representing an angle of π radians. If your nautilus shell half coils clockwise, then the successive angles for your measurements actually are increasing by increments of - π/4 (negative) radians, but you can think about all angles with positive values for simplicity (after all, the other half of the shell would have been identical, except that it would have coiled counterclockwise).**
- Note that a graph of your data is produced in the Excel spreadsheet as you enter your measurements. This graph represents the growth of the nautilus's shell, in terms of length, as it adds new chambers around the spiral.
- Does this graph appear to show a linear relationship between the length of a radius and its corresponding angle?

  Your answer to the previous question should have been "no." Though the radius increases with angle, the relationship is not linear. You should notice that the curve is J-shaped, which represents **exponential growth**. This should make sense, as exponential growth represents a situation in which the growth rate of a variable is proportional to its current value.

- Notice that on the graph produced in the Excel spreadsheet, in which $\boldsymbol{r}$ is plotted as a function of $\boldsymbol{\theta}$, we are plotting polar coordinates ($\boldsymbol{r}$ and $\boldsymbol{\theta}$) in the Cartesian coordinate system. What would happen if we converted our original polar coordinates from our data to Cartesian (parametric) coordinates, and plotted them? Let's find out!

Converting polar coordinates to parametric coordinates is a matter of converting values of $\boldsymbol{r}$ and $\boldsymbol{\theta}$ to values of $\boldsymbol{x}$ and $\boldsymbol{y}$. As you might imagine, since polar coordinates rely on angles, the way to convert values of $\boldsymbol{r}$ and $\boldsymbol{\theta}$ to values of $\boldsymbol{x}$ and $\boldsymbol{y}$ involves some trigonometric functions. Though we have not discussed the **sine** and **cosine** functions, they are the functions used to convert polar coordinates to parametric coordinates, as follows: $\boldsymbol{x = r\cos\theta}$, and $\boldsymbol{y = r\sin\theta}$.
In the Excel spreadsheet, formulas have already been defined to calculate these values for you for your first data point (the radius of the nautilus shell at an angle of 0 radians). You can easily have Excel quickly calculate all of the rest of these values for you, by using the following instructions:

1. Click on the first cell under the column labeled "x" to highlight it, and drag the highlighted selection over to also include the first cell under the column labeled "y".
2. You should notice that the highlighted selection is now surrounded by a box with a thick black border. If you hover over this selection, you will also notice that the bottom right corner of this selection is a small black square.
3. If you click this small black square, and drag the mouse downward to include all of the rows in the "$\boldsymbol{x}$" and "$\boldsymbol{y}$" columns for which you also have corresponding data in the "$\boldsymbol{r}$" and "$\boldsymbol{\theta}$" columns, you should see that these cells automatically get filled in with the Cartesian coordinates, which were converted from your original polar coordinates.
4. A new graph should be displayed after you have calculated the Cartesian coordinates of all of your data.
5. Compare your nautilus shell to this graph.

Q18. How are the curvature of your nautilus shell and that of this new graph similar? Are they different in any way? Why might this be the case?

It is instructive when thinking about logarithmic spirals to consider how the distance from the origin to successive points along a radial spoke increases. Your team will now examine your nautilus shell to estimate this factor $\boldsymbol{k}$ for the spiral curvature of the shell. Doing so would be of interest to a biologist, as this factor would tell us something about the rate of the nautilus' growth. Knowing such information would allow them to do interesting things such as make predictions about how big the nautilus would be at a given age, or to estimate the age of the nautilus based on its size, since the nautilus typically adds chambers to its shell in regular intervals.

Instructions for calculating *k* for the spiral of your nautilus shell

- Look at the data you collected to create your plot of r versus θ.
- Record the radial measurements for each of the points on your shell's spiral intersected by the radial gridline representing angles of 0, 2π, and 4π in the table below, with the innermost point (closest to the origin) in the column labeled P_1, the next point outward from the center in the column labeled P_2, and the outermost point on the spiral along this spoke in the column labeled P_3.
- Repeat this process for each of the other radial spokes, corresponding to the angular measurements represented by each spoke. You may not be able to fill in distances for three points for each radial spoke. Just fill in distances for as many of these points as possible.
- For each spoke, calculate the two values of *k* (k_1 and k_2) by which distances from the origin increase along that radial spoke.
- Find the mean (average) value of *k* from your data. This average value would be a fairly good estimate of the factor at which the radius to a point on the nautilus' spiral increases when one moves along a radial spoke from center of the spiral outwards (representing moving along the spiral in successive increments of 2π radians).

Radial Spoke	**Angles**	P_1	P_2	P_3	k_1 $(= P_2/P_1)$	k_2 $(= P_3/P_2)$
1	0, 2π, 4π					
2	0.25π, 2.25π, 4.25π					
3	0.50π, 2.50π, 4.50π					
4	0.75π, 2.75π, 4.75π					
5	π, 3π, 5π					
6	1.25π, 3.25π, 5.25π					
7	1.50π, 3.50π, 5.50π					
8	1.75π, 3.75π, 5.75π					
					Average *k* =	

Let's take a moment to again return to the polar equation for a logarithmic spiral:

$$r = ce^{\theta \cot \alpha}$$

Q19. Using the equation above, find an equation expressing the constant k in terms of the constant angle α. **HINT:** Think about two points on a radial spoke, with angular measurements of θ and $\theta + 2\pi$! **Check your answer in the answer section of this book.**

Q20. Find an equation to solve for α, in terms of k, using the equation from the previous question. **Check your answer in the answer section of this book.**

Now that you have solved for α in terms of k, you can use a scientific calculator or the Excel spreadsheet to calculate the constant angle for the logarithmic spiral approximated by your nautilus shell. Make sure that you are aware of whether your calculator is using degrees or radians to do this calculation! Excel does calculations of trigonometric functions using radians, and it is important that in using polar equations, angles are measured in radians. Now you should try to see if this angle is actually close to angles formed by the radii and tangents to radii at those points on your nautilus shell's spiral.

Instructions for measuring angles formed by radii and tangents on the curvature of your nautilus shell

- Once you have found the angle α above, convert this answer to degrees (if it is not already in degrees).
- Pick a point on the spiral that lies along one of the radial gridlines drawn on the container housing your nautilus shell.
- Using one of the rubber bands provided in the box, stretch this across the container, so that the rubber band forms a line tangent to the curve at your selected point. Remember, a tangent line to a curve at a particular point should **ONLY** touch pass through the curve at that point.
- Using the provided protractor, measure the angle formed by this tangent and the radius, and record this measurement.
- Repeat this process at least 3 more times, using different radial gridlines and different points along the spiral.
- Answer the following questions about your results.
    - Are all of the separate values of k that you calculated for your spiral (in the previous exercise) similar?
    - Are the values of your measured angles similar to one another?

- Are those angles close to the calculated value of the constant angle in a perfect logarithmic spiral?

Q21. If you answered no to any of these questions, why do you think this might be the case?

Calculating c for the logarithmic spiral approximated by your nautilus shell
To refresh your memory, the equation we have used to describe a logarithmic spiral (in polar coordinates) is $\boldsymbol{r = ce^{\theta \cot \alpha}}$.

Up to this point, you already know or have solved for many of the variables in this equation ($\boldsymbol{r}$, $\boldsymbol{e}$, $\boldsymbol{\theta}$,and $\boldsymbol{\alpha}$). However, we have not yet solved for the constant $\boldsymbol{c}$ in this equation, but this is easy enough to do:

- Using Excel or a scientific calculator, calculate $\boldsymbol{e^{\theta \cot \alpha}}$ for all values of the angles ($\boldsymbol{\theta}$) for which you have already collected data, using your calculated value of $\boldsymbol{\alpha}$ from earlier in the exercise.
- For each of your data points, divide the actual measurement of the radius ($\boldsymbol{r}$) by the result of $\boldsymbol{e^{\theta \cot \alpha}}$. Each time you do this, you are calculating an estimate of $\boldsymbol{c}$ for that particular data point.
- Calculate the average value for all of your values of $\boldsymbol{c}$.
- Now that you have calculated an average value of $\boldsymbol{c}$, plot (on the same graph as the plot of your $\boldsymbol{r}$ and $\boldsymbol{\theta}$ data) the graph of the equation $\boldsymbol{r = ce^{\theta \cot \alpha}}$, calculating values of $\boldsymbol{r}$ based on $\boldsymbol{\theta}$, and using your calculated values of $\boldsymbol{\alpha}$ (in radians) and $\boldsymbol{c}$.
- Answer the following questions about your results:
  - Does the plot of this equation fit your actual data fairly well?
  - Based on your answer to the previous question, are you now fairly convinced that the shell of the nautilus grows in a pattern that closely approximates a logarithmic spiral?

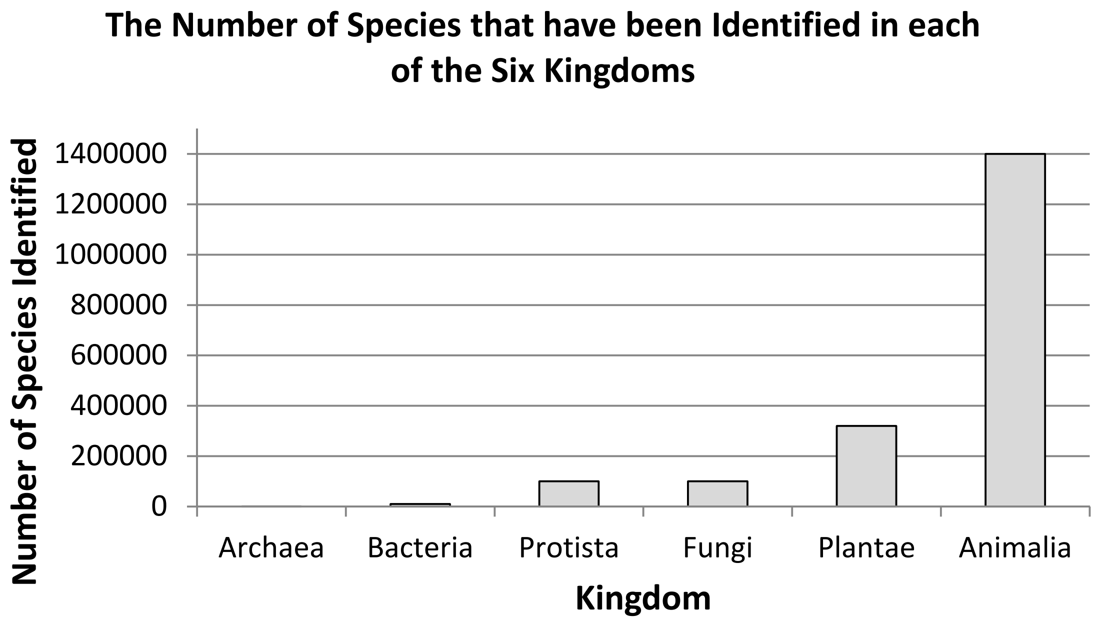
Exercise 9c was adapted from the following sources:

Baggett, P. & A. Eherenfeucht. 2006. “Chambered Nautilus”. Breaking Away from the Math Book. 20 June 2006. New Mexico State University. 12 May 2010. <http://www.math.nmsu.edu/~breakingaway/Lessons/chnautilus1/chnautilus.html>

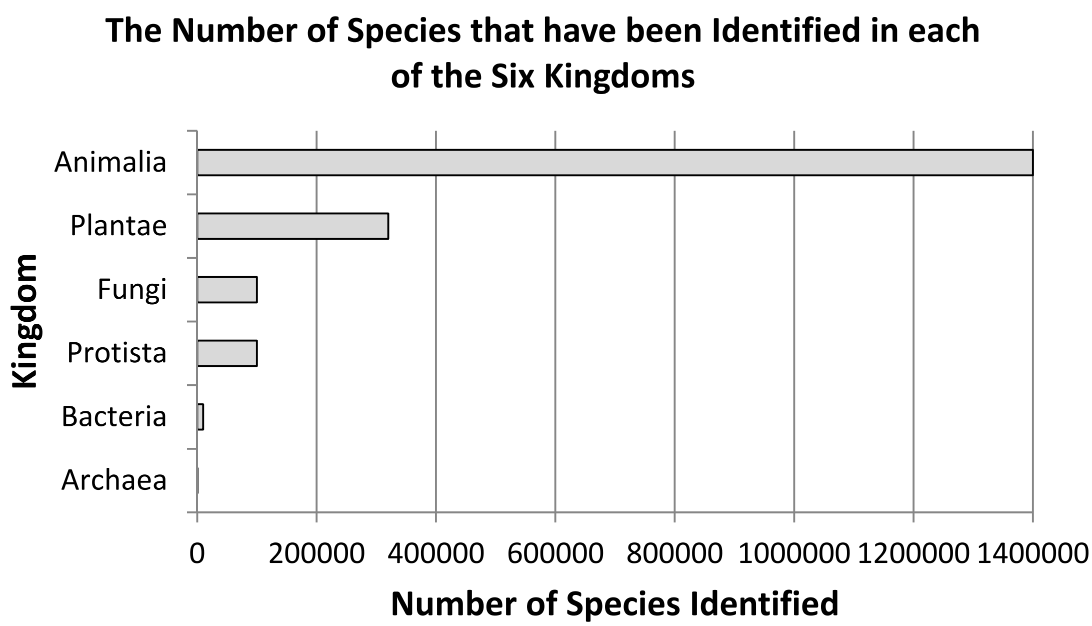
Moore, L., D. Smith, & B. Mueller. 2001. The Equiangular Spiral. *The Connected Curriculum Project*. 07 September 2004. Duke University. 12 May 2010. <http://www.math.duke.edu/education/ccp/materials/mvcalc/equiang/index.html>

Answers for Exercise 1: Graph that Abundance

A. Vertical Bar Graph

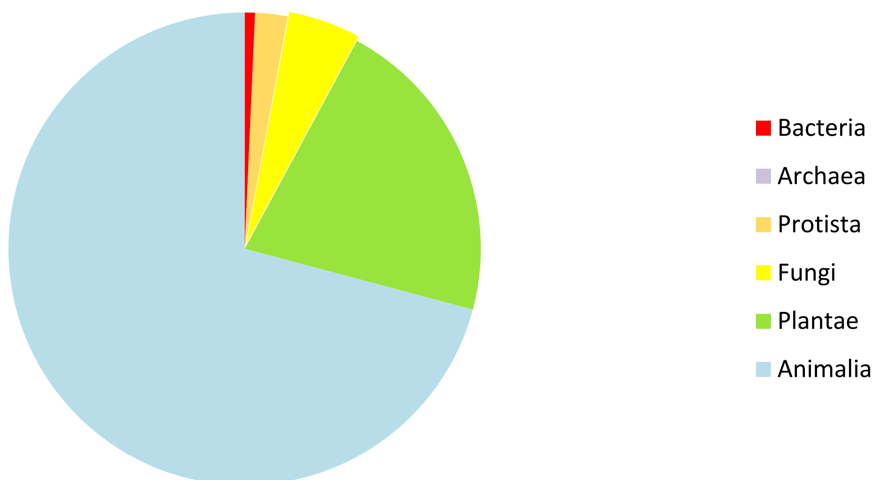


B. Horizontal Bar Graph



C. Pie Graph/Chart

Number of Species Identified in Each of the Six Kingdoms



Q1. Which grade has the most students? Which grade has the second most students? Which graph makes it easier to see the answer to this question?

The fifth grade has the most students. The fourth grade has the second most students. It is easier to see that this is the answer by looking at the bar graph.

Q2. How are the students distributed among the five grades? That is, do a few of the grades contain most of the students or are the students fairly evenly distributed amongst all of the grades?

The students are fairly evenly distributed among all of the grades. This is easier to see by looking at the pie chart.

Q3. Approximately how many students are in the third grade? Which graph did you use to answer this question? Could you have used the other graph to answer the question? Why or why not?

There are about 630 students in the third grade. We used the bar graph to answer this question. We could not have used the pie chart, because the pie chart displays the fraction of total students in each grade, and not the number of students in each grade.

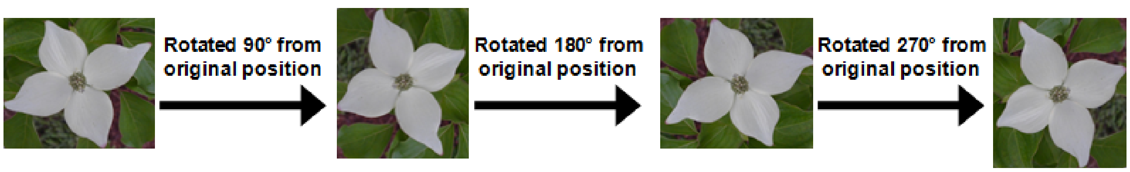
Q4. What kinds of questions are easier to answer by looking at a bar graph? What kinds of questions are easier to answer by looking at a pie chart?

Bar graphs can be used to find or estimate exact data values. Pie charts can be used to describe how data is distributed.

<u>Answers to Exercise 2: What's that Reflection?: Animal Symmetry</u>

Q1. How many rotational positions preserve the appearance of the dogwood flower? What are those positions, in terms of angles?

A rotation of 90° preserves the dogwood flower's appearance, as will any rotation that is a multiple of 90°. For example, rotations of 180° and 270° will also preserve the dogwood flower's appearance. A rotation of 360° would also preserve the dogwood flower's appearance, as this would place the flower in its original position.



Q2. How many rotational positions preserve the appearance of the comb jelly or sea walnut?

A rotation of 180º preserves the appearance of the comb jelly (as does a rotation of 360º, which would be the same as not rotating it at all).

Q3. Find all of the angles of rotation less than 360° that preserve the appearance of this sea urchin skeleton.

The sea urchin skeleton has five nearly identical sectors, and so a rotation of 360°/5=72° will preserve its appearance, as will any rotation that is a multiple of 72° (rotations of 72°, 144°, 216° and 288°).

Q4. Does the dogwood flower also have reflection symmetry? If so, how many planes of symmetry does the dogwood flower have?

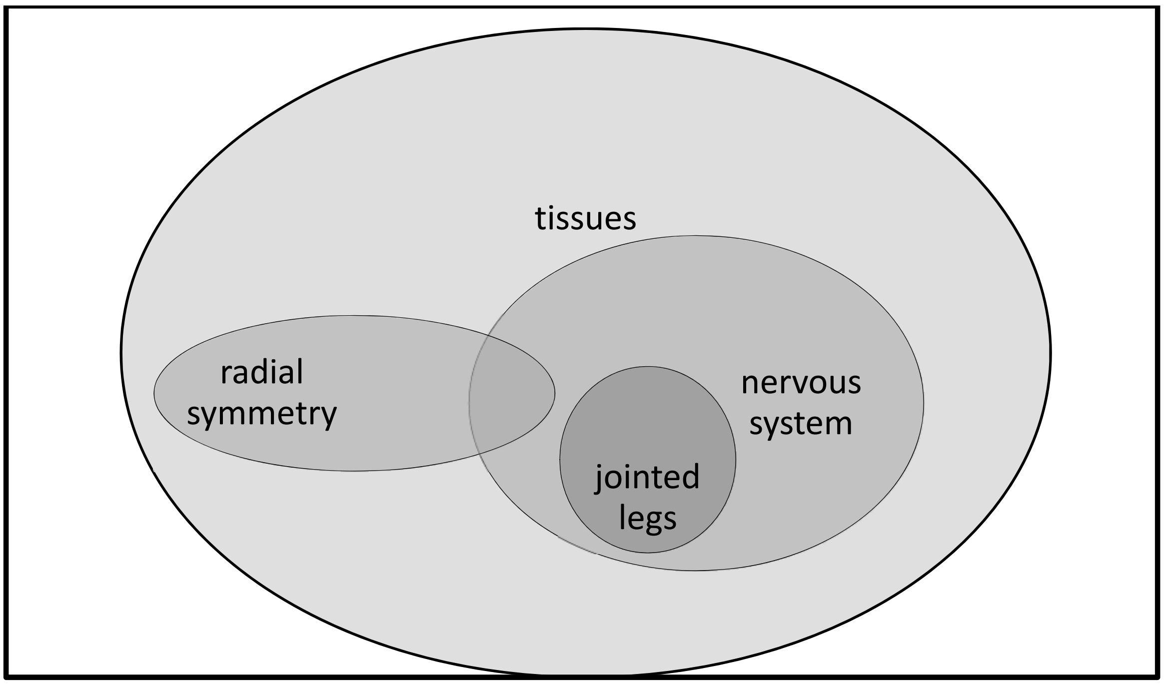
Yes. The dogwood flower also has reflection symmetry, with four planes of symmetry (two dividing opposite pairs of petals in half, and two passing between adjacent petals).

<u>Answers to Exercise 4: Diagram those Traits</u>

Q1. Which of the following animals belongs in the region of overlap?
b) Roundworm

Q2. Which of the following animals belongs in the solid blue region?
c) Insect

Q3. Draw a Venn diagram with the following regions: jointed legs, tissues, nervous system, radial symmetry. Which of these regions contains the most animals?



The region labeled tissues contains the most animals because all of the other regions are contained in this region.

Q4. Use the diagram to decide which member of the pair contains the most animals, or else state that this cannot be determined by looking at the diagram.

- **radial symmetry or nervous system:** cannot be determined
- **jointed legs or radial symmetry:** cannot be determined
- **nervous system or jointed legs:** nervous system

<u>Answers for Exercise 6: Who's in that Tree?</u>

Q1. Which animals groups are displaced in this tree from where they are located in the tree based on development?

The arthropods, which have a true coelom or body cavity developed to house complex organ systems, have been removed from the lineage containing other groups that have a true coelom (molluscs and segmented worms) and placed into a lineage that includes organisms that have a pseudocoelom, or a body cavity that mainly provides shape in the absence of a skeleton. This new category contains animal types that share the same gene in common, as well as a cuticle that is shed and replaced periodically as the animal grows.

Q2. How might the validity of the two alternative trees be tested?

One thing that can be done is to examine more genes to determine whether the relationships suggested by the sequencing of one gene are supported by the sequencing of other gene sequences. In fact, a study doing just that was recently published in 2008 by Dunn et al., and this publication is available on the teacher CD included with this unit.

<u>Answers to Exercise 7: What's that Animal?</u>

Your mystery animal could be a horseshoe crab, which is not actually a true crab at all. It is an arthropod in the subphylum Chelicerata, meaning it is more closely related to the spiders and other arachnids than it is to the crustaceans (crabs and their relatives). Horseshoe crabs are sometimes called "living fossils" because their early relatives, which looked almost identical to the four currently existing species, inhabited the Earth 100 million years before the dinosaurs existed. The North American species *Limulus polyphemus* reaches 2 feet in length and is best known for their impressive yearly spawning at several localities along the Atlantic coast of the U.S. At particular times of the year, thousands of individuals crowd up on the beaches at high tide. The female scoops out a hole in the sand and lays thousands of eggs, which the male fertilizes, before both adults head back to deep water. The eggs are an important source of food to shore birds. If your mystery animal does not look like a horseshoe crab, look at the other possible mystery animal below.

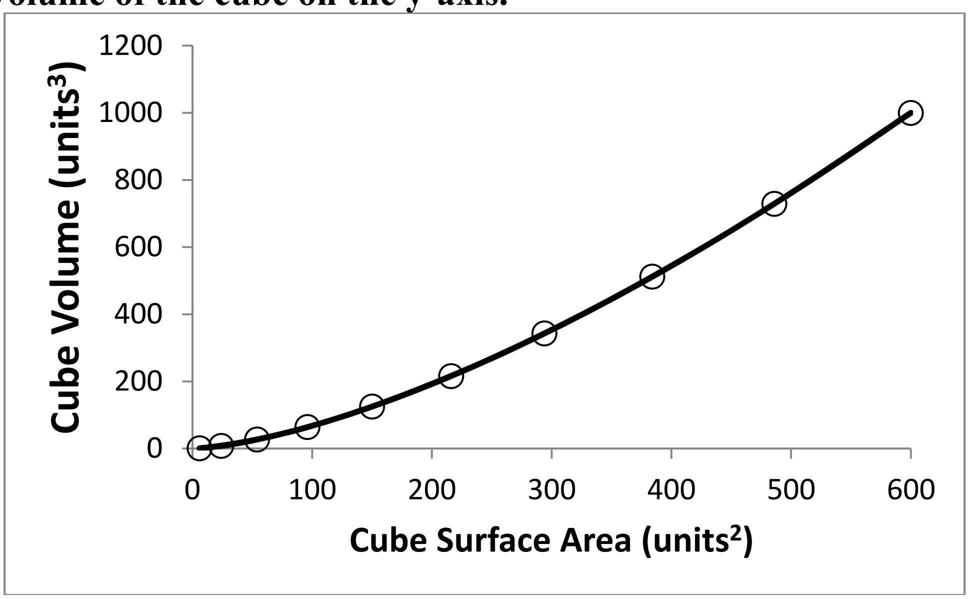
If your mystery animal has a cucumber or cigar shape, it is a sea cucumber, which is a member of the Phylum Echinodermata, making it a relative (though a strange-looking one!) of the starfish and sea urchins. Sea cucumbers belong to the Class Holothuroidea, and are sometimes called the "earthworms of the ocean floors". Though they are not closely related to earthworms at all, they perform a role similar to that of earthworms in terrestrial systems, in that they help recycle dead organic matter into a form that can be used by plants. They break down animal waste and algae into smaller pieces that can be decomposed by bacteria. The echinoderm's tube feet are modified into tentacles which it uses to grab organic material. The sea cucumber is a slow-moving animal that is often partially buried in the detritus on which it feeds. Since it cannot escape a predator that chances upon it, it may instead eject sticky Cuvierian tubules from its anus to entangle the predator, giving the sea cucumber a chance to try to make a slow escape. There are about 1400 species of sea cucumbers, some of which are served stuffed in Chinese restaurants.

Answers for Exercise 8: Pass that Gas!

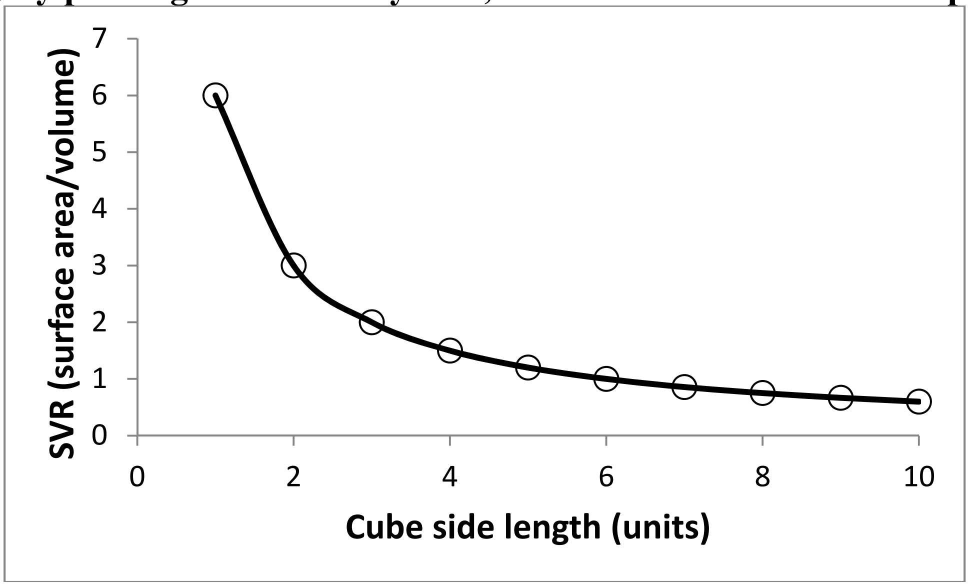
Q1. Complete the following table, calculating the values of surface area and volume for cubes of a given side length.

Side length of a cube (in units)	Surface area of the cube (in units^2)	Volume of the cube (in units^3)
1	6	1
2	24	8
3	54	27
4	96	64
5	150	125
6	216	216
7	294	343
8	384	512
9	486	729
10	600	1000

Q2. Make a plot of these data, with the surface area of the cube on the x-axis, and the volume of the cube on the y-axis.



Q3. Now make a plot of the relationship between SVR and cube size (side length, *s*) by plotting SVR on the y-axis, and s on the x-axis in a new plot.



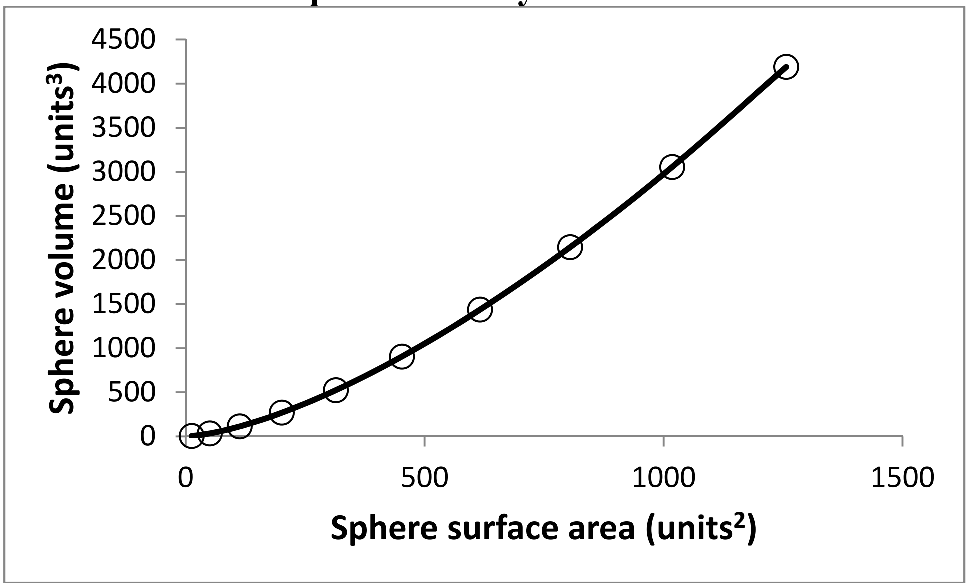
Q4. How does surface area to volume ratio (SVR) of the cube change as the cube increases in size?

As the cube increases in size, SVR decreases rapidly, since volume increases as the cube of ***s*** (s^3), and surface area increases as a function of the square of ***s*** (s^2).

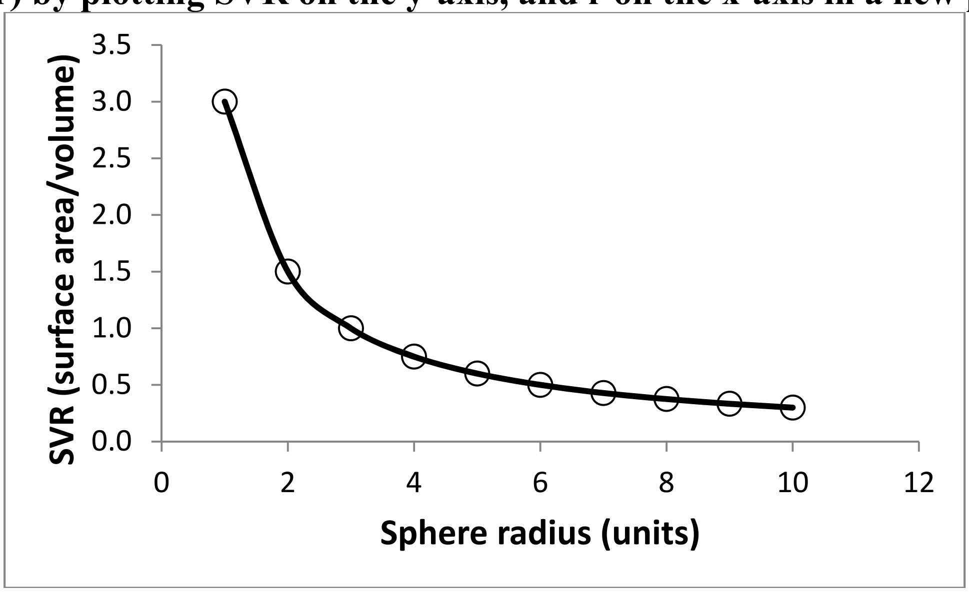
Q5. Complete a table similar to that constructed in Q1, calculating the surface areas and volumes of spheres with radii from 1-10 units.

Radius of a sphere (in units)	**Surface area of the sphere (in units^2)**	**Volume of the sphere (in units^3)**
1	12.6	4.2
2	50.3	33.5
3	113.1	113.1
4	201.1	268.1
5	314.2	523.6
6	452.4	904.8
7	615.8	1436.8
8	804.2	2144.7
9	1017.9	3053.6
10	1256.6	4188.8

Q6. Make a plot of these data, with the surface area of the sphere on the x-axis, and the volume of the sphere on the y-axis.



Q7. Now make a plot of the relationship between SVR and sphere size (radius, r) by plotting SVR on the y-axis, and r on the x-axis in a new plot.



Q8. Compare your plots that you constructed for the cube (in Q2 and Q3) to those that you just constructed for the sphere (in Q6 and Q7). Are they similar in shape?

Yes. The plots are similar in shape for both the cube and the sphere.

Q9. From these plots, what general statement can you make about the relationship between surface area and volume of shapes as they increase in size?
As three-dimensional shapes increase in overall size, the surface area to volume ratio gets dramatically smaller.

Q10. Aside from developing some form of active pump, what can a cell do to overcome the problem of decreasing rate of gas exchange with increasing size?
Cells solve the decreasing gas exchange with increasing size problem in two ways. First, they can undergo cell division. Secondly, they may take on shapes other than that of a sphere, as these may have more favorable surface to volume ratios.
You can explore other basic shapes to find the one that has the most similar ratio of surface area to volume, approaching the problem from geometry, or from researching the variation in cell shape that exists in nature.

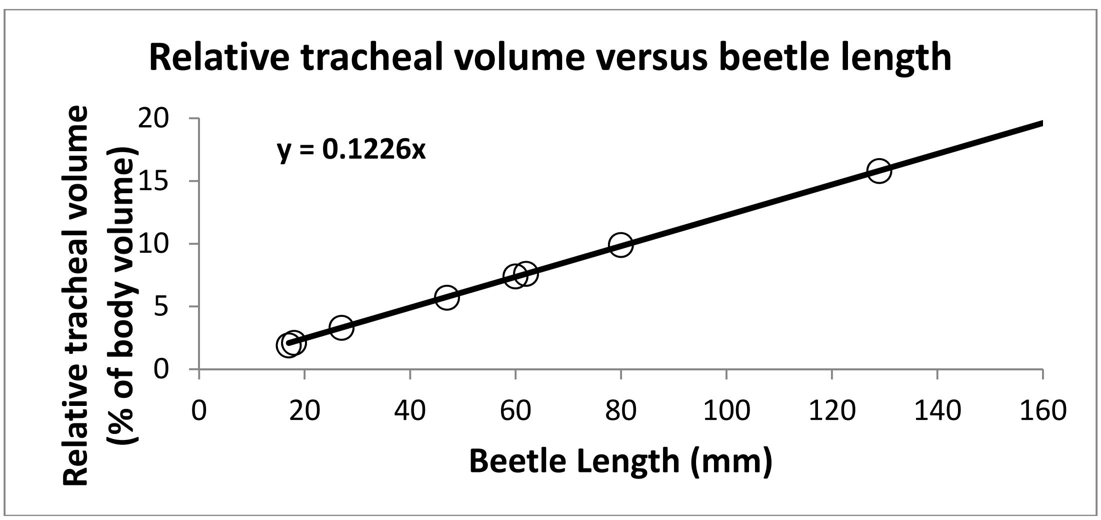
Q11. Which organisms in your box complete gas exchange through simple diffusion across a body surface?
Though sponges (phylum Porifera) also do not have gills or lungs, the beating of flagella on their collar cells creates currents that draw water (which contains dissolved oxygen) through their porous body walls. Thus, this would not be considered passive diffusion. Members of the phylum Mollusca (and aquatic members of the phylum Arthropoda) conduct gas exchange by drawing water over their gills, while terrestrial arthropods rely on spiracles, and chordates (phylum Chordata) rely on gills or lungs. Most mollusks move water over their gills through the beating of cilia (small eyelash-like structures on some cells), which creates a current, while cephalopods (also mollusks) and chordates typically move water over their gills through muscular contractions. Members of the phylum Echinodermata conduct gas exchange by actively moving water through their water vascular systems. Thus, all of these methods would not be considered simple, passive diffusion.

However, organisms in the phyla Cnidaria, Platyhelminthes, Nematoda, and Annelida complete gas exchange through simple diffusion, as they do not have gills or lungs. Due to the lack of active means of obtaining oxygen, many organisms in these groups display body plans that increase their surface area to volume ratio, such as long, thin shapes, such as that observed in flatworms. However, a higher surface area to volume ratio also results in an increased risk of dessication (water loss) through the body surface, so many of these organisms are restricted to aquatic or moist terrestrial habitats, though the presence of a cuticle in nematodes and annelids allows them to live in slightly drier habitats than cnidarians and flatworms.

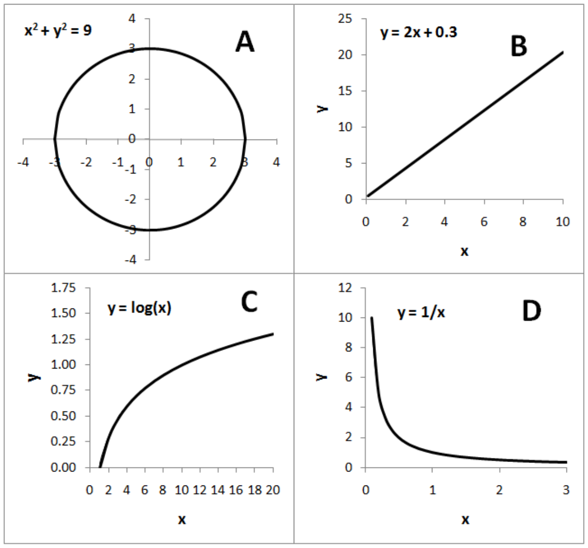
Q12. Consider the problem terrestrial (land dwelling) insects such as the praying mantis or ant seen in horror flicks have. Why are they unable to exchange gas across their body surfaces?
Terrestrial insects are unable to exchange gases directly across their body surfaces because of the presence of the waxy cuticles covering their exoskeletons. Though this cuticle prevents water loss through their body surfaces, it also is impermeable to gases.

Q13. What is a general statement that can be made about the relationship between insect body size and tracheal volume (relative to total body volume)?
As insect body size increases, so does the relative tracheal volume.

Q14. Make a graph of the data above, plotting beetle length on the x-axis, and relative tracheal volume on the y-axis. Draw an approximate line of best fit that passes as closely to each of your data points as possible.



Q15. What is the shape of the graph of relative tracheal volume versus beetle length?



The graph of this relationship is almost perfectly linear, and can be described by the equation for a line: $\boldsymbol{y = mx + b}$. In this case, ***y*** is relative tracheal volume, ***x*** is beetle length, ***m*** is the slope of the line, and ***b*** is the y-intercept (where the line crosses the y-axis, when ***x*=0**). The shapes of the other equations presented as possible answers to this question are shown at the left.

Q16. See if you can calculate the slope of the line representing the relationship between relative tracheal volume and beetle length. For simplicity, assume that the y-intercept of this line is at 0, since a non-existent beetle would have no tracheae.

Using the information from the question (assuming a y-intercept of 0), we can set ***b*** equal to zero in the equation for the line. We can then pick any corresponding pair of values of ***x*** (beetle length) and ***y*** (relative tracheal volume) in the data table to calculate the slope of this line, which is approximately equal to 0.1226.

Q17. Based on this data, what is the *theoretical* maximum size of a beetle? Hint: What if a beetle's body volume consisted of nothing but tracheae?

If a beetle were composed of nothing but tracheae (relative tracheal volume would be equal to 100%), we can solve for the corresponding beetle size. Since we have already determined that the equation expressing relative tracheal volume as a function of length as $\boldsymbol{relative\ tracheal\ volume = 0.1226(beetle\ length)}$, we can solve for beetle length for a given tracheal volume by dividing both sides of the equation by the slope of the line (0.1226):

$$\boldsymbol{beetle\ length = \frac{relative\ tracheal\ volume}{0.1226}}$$

If a beetle were composed of nothing but tracheae (relative tracheal volume were equal to 100% of total body volume), the maximum beetle length would thus be equal to

$$\boldsymbol{beetle\ length} = \frac{\boldsymbol{relative\ tracheal\ volume}}{\mathbf{0.1226}} = \frac{\mathbf{100}}{\mathbf{0.1226}} = \mathbf{815.66}\ \boldsymbol{mm}.$$

This would be a very large beetle (almost 3 feet long), but still nowhere nearly as large as the giant insects from horror and science fiction movies!

Q18. Given that the largest beetle alive today (*Titanus giganteus*, a South American long-horned beetle in the family Cerambycidae), is approximately 170mm in length, use your answer to the previous question to calculate the approximate percentage of that species' body volume occupied by tracheae.
Using the previous equation from **Q13** and **Q14**, we can solve for the relative tracheal volume in *Titanus giganteus* as follows:

$$relative\ tracheal\ volume = 0.1226(beetle\ length) = 0.1226(170) = 20.84\%$$

Q19. What do you think limits the body volume that an insect can devote to the tracheal system?
As we have learned, of course insects need to breathe, and thus must have tracheae. However, insects also have to eat and reproduce (among other things), as well as have structures that allow them to do so. Therefore, an insect can't be composed of nothing but tracheae, as there also has to be some body volume devoted to these other important structures! Thus, the amount of body volume that a given type of insect can devote to tracheae is constrained (limited) by other aspects of that insect's lifestyle.

Q20. If you assume that the maximum relative tracheal volume in insects as a whole is equal to the value that you calculated in Q16, and the relationship between length and relative tracheal volume has a slope of 0.056, what is the maximum length of this type of insect? What does this insect look like?
If we solve for the insect's length as above, in **Q15**, though using this different slope, we can solve for the maximum length of that type of insect by also using the maximum value of relative tracheal volume as calculated in **Q16**, as follows:

$$insect\ length = \frac{20.84}{0.056} = 372.14\ mm$$

We thus know that this is a very long insect, over 14 inches in length. One way of thinking about the actual shape of this insect is to again use our knowledge of surface area to volume, as well as the slope of this line. Since the slope of this line is lower than that for beetles, meaning that relative tracheal volume increases less rapidly with increasing insect size, so this insect likely has a greater surface area to volume ratio (SVR).

One way of increasing surface area to volume ratio is through long, thin structures. Thus, we might deduce that this is a very long, thin insect, such as a walking stick (order Phasmatodea). In fact, this length corresponds to the length of the longest stick insect, Chan's Megastick (*Phobaeticus chani*), pictured below, which has a body length of 360mm. That is twice as long as the largest beetle!

Q21. During the Carboniferous Period (350 million years ago), there were insects much larger than any found on earth today. Develop a hypothesis to explain this observation. How would you test this hypothesis?
One possible explanation is that a higher concentration of oxygen in the atmosphere during that period of time allowed insects to reach much larger sizes. One way of testing this hypothesis would be to measure the amounts of various minerals containing oxygen in rock layers of different ages. In fact, several such studies consistently suggest that Earth's atmosphere contained a much higher concentration of oxygen during the Carboniferous (approximately 35%, compared to the modern value of around 21%). However, many studies of insect physiology have shown that even the extra oxygen during that time still is not enough to explain the much larger size of many Carboniferous insects, including dragonflies

with 3 foot wingspans. Can you think of any other hypotheses, or how to test them?

<u>Answers for Exercise 9: Follow that Spiral!</u>

Q1. Examine the examples of spirals pictured below. How many of these can you identify?

Below are the identities of each of the natural and man-made spirals in the introduction to this exercise.

A	Spiral staircase
B	Spring coil
C	Galaxy
D	Anemometer
E	Fern fiddleheads
F	Compact fluorescent light bulb
G	Tornado
H	Vine tendril
I	Mountain goat horn
J	Snail shells
K	Pine cone
L	Rose flower
M	Turkey feather fungus
N	Bolt & screws
O	Bat exodus pattern from a cave

Q2. Although we can look at something and recognize it as having a spiral, can you describe a spiral in words?

A spiral is a structure or path that travels around a central point in a continuous series of loops that either increase or decrease in diameter with each coil.

Q3. Does a snail shell have symmetry?

The snail is unusual in that most molluscs are bilaterally symmetric animals, but the snail shell is asymmetrical and internally, so is the snail. This asymmetry is the result of a developmental process called torsion, in which the snail's organ system is twisted, some of its organs are lost, and the spiral shell is created. **Note:** While a snail's shell does not exhibit bilateral or radial symmetry, the spiral of a snail's shell does exhibit *scale symmetry*, which is described under the exercise on logarithmic spirals.

Q4. What purposes do you think this spiral structure might serve for a snail?

Again, the spiral shell of a snail is a result of the developmental process of torsion. Why does the snail go through torsion? The snail may have developed torsion as a defense against predators. Torsion allows the larval snail to fully retract its head into its shell first, thus improving its chances of surviving an attack. Before torsion occurred, the larval snail's tail end would retract into the shell first and the head last. Which is more important to survival: losing one's tail or one's head? Clearly, it would be better to do without a piece of one's tail!

Q5. Does your ranking according to apparent size agree with your size measurements? Why might your visual rankings differ than rankings based on your measurements?

Students' answers to this question may vary, depending on whether their visual size rankings agree with their ranks based on actual measurements. If these rankings do not agree, this could be because students' visual rankings may have been based on a particular trait (such as shell length, width, etc.), while the trait they actually measured may have resulted in different rankings. This is because different size measures of various parts of the shell may or may not be correlated with the trait they used in their visual rankings.

Q6. Since the equation for the circumference of a circle is $\boldsymbol{C = \pi d}$, and the diameter of a circle is equal to two times its radius ($\boldsymbol{d = 2r}$), how would you solve for the radius to help you calculate the volume?

You could first substitute 2r for d in the first equation to obtain $C = \pi(2r)$. If you then divide both sides of the equation by 2π, you obtain the following: $r = \frac{C}{2\pi}$. Alternatively, if you had obtained the diameter by measuring a traced outline of the shell, you could simply divide the diameter by 2, since the radius of a circle is equal to half its diameter.

Q7. How is a snail's shell volume related to its body size?

The body size of a snail should be positively correlated with shell volume. In other words, the larger the volume of the shell, the larger the body of the snail that inhabited it.

Q8. What is the factor by which the value of a nickel is less than the value of a dime?

Remember, if y is greater or less than x by a factor of c, then $y = cx$. In this case, we can substitute the values of a nickel for *y*, and the value of a dime for *x*, to solve for *c*:

$$\boldsymbol{y = cx}$$

$$\boldsymbol{5 = c(10)}$$

$$\boldsymbol{c = \frac{5}{10} = 0.5}$$

Q9. What is the factor by which the value of a nickel is less than the value of a quarter?

$$\boldsymbol{c = \frac{5}{25} = 0.2}$$

Q10. What is the factor by which the value of a quarter is greater than the value of a nickel?

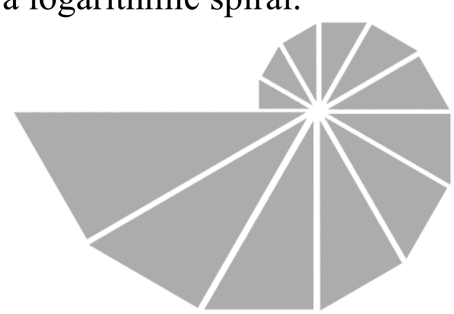
$$\boldsymbol{c = 5}$$

Q11. Complete the following sentence: If *x* is greater than *y* by a factor of *c*, then *y* is less than *x* by a factor of ___ .

Using the answers to **Q9** and **Q10** above, we can see that the answer is $\frac{1}{c}$.

Q12. What sort of shape does the completed puzzle form? Compare the completed puzzle to the nautilus shell in your box. Are they similar?

The completed nautilus puzzle should look like the one below. In the completed puzzle, you should see that the hypotenuse (the longest side on each right triangle) of any triangle matches up to the second longest side on the next largest triangle. The completed puzzle, like the actual nautilus shell, approximates a logarithmic spiral.



Q13. Are these values similar for the smallest, medium, and largest angles in each of the nautilus puzzle triangles?

All of the values of the angles on the nautilus puzzle triangles are the same, with measurements of 30º, 60º, and 90º.

Q14. Are all of the ratios of corresponding sides between a larger triangle and the next smaller triangle close to the same value?

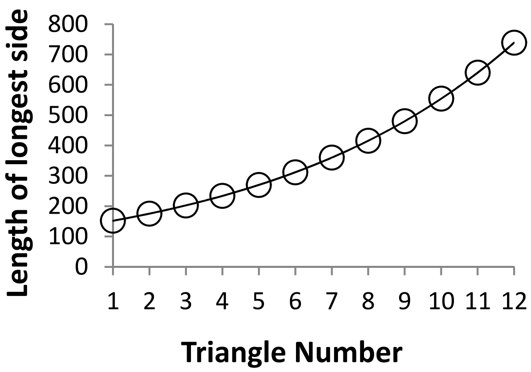
Though your measurements might differ slightly due to possible rounding of measurements, accuracy of the ruler, etc., all of the ratios should be close to around 1.15.

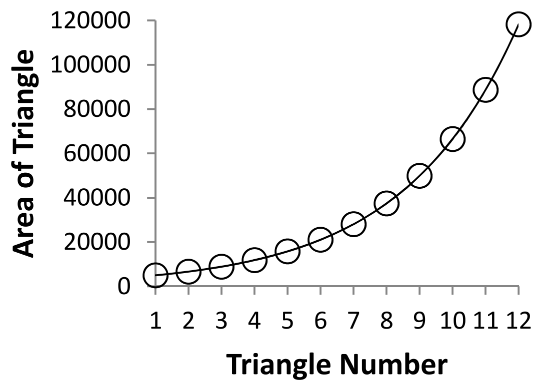
Q15. Based on your answers to the previous questions, would you say that the triangles are all similar triangles? How does this relate to the growth observed in the nautilus?

Based on the previous information in the answers to **Q5** and **Q6**, it should be clear that all of the triangles are indeed similar. Similar triangles have exactly the same shape, and differ only in size. This puzzle thus directly reflects the isometric growth observed in the nautilus, which changes only in size, but not body proportions, as it grows.

Q16. What is the shape of this plot?

Below are two example plots of measures of triangle size versus triangle number. In each of the following graphs, lengths and areas were calculated in terms of pixels on the figure used to make the puzzle. The values of student measures of triangle size will be in millimeters, and thus their values plotted on the y-axis of their graphs will differ. However, no matter the units in measuring triangle size, students will still obtain graphs of similar shape. They should notice that each curve is J-shaped, which represents **exponential growth**. This should make sense, as exponential growth represents a situation in which the growth rate of a variable is proportional to its current value, which is exactly the type of growth observed in a real nautilus shell. Triangle number can be further related to the growth of a nautilus shell, as each larger triangle represents a new chamber formed by the nautilus as it grows. Since the nautilus adds new chambers to its shell at fairly regular intervals, triangle number can be viewed as representing a certain unit of time, with a new chamber being added at each time "step".





Q17. What is the angle between point C and the x-axis?

$$\theta + 4\pi$$

Q18. How are the curvature of your nautilus shell and this new graph similar? Are they different in any way? Why might this be the case?

Your Excel graph may coil in the opposite direction as the spiral on your half of the nautilus shell. However, the other half of the shell would coil in the same direction as your graph, as it is the mirror image of the half in your box.

Q19. Using the equation on the previous page, find an equation expressing the constant *k* in terms of the constant angle *α*.

If you use r_2 to represent a larger radius along a radial spoke, which is 2π revolutions outwards from a smaller radius r_1 (at angle θ), we can express both r_2 and $r_1$as follows:

$$r_1 = ce^{\theta \cot \alpha}$$
$$r_2 = ce^{(\theta + 2\pi) \cot \alpha}$$

Since k represents the factor by which r increases with each 2π radians around the origin, we can solve for k as the ratio between r_2 and r_1:

$$k = \frac{r_2}{r_1} = \frac{ce^{\theta \cot \alpha}}{ce^{(\theta + 2\pi) \cot \alpha}}$$

In this expression, c will disappear, since it is in both the numerator and denominator, leaving us with

$$k = \frac{e^{\theta \cot \alpha}}{e^{(\theta + 2\pi) \cot \alpha}}$$

Using the laws of exponents, which state that when dividing a base with a given exponent by the same base with a different exponent, the result is equal to the base raised to the power of the first exponent minus the second, which leaves us with

$$k = e^{2\pi \cot \alpha}$$

Q20. Find an equation to solve for α, in terms of k, using the equation from the previous question.

Since we already know that $k = e^{2\pi \cot \alpha}$,

we can get rid of the exponent by taking the natural logarithm of both sides:

$$\ln(k) = \ln(e^{2\pi \cot \alpha}) = 2\pi \cot \alpha$$

If we now divide both sides by 2π, we've almost solved for α:

$$\frac{\ln(k)}{2\pi} = \cot \alpha = \frac{1}{\tan \alpha}$$

Thus,

$$\frac{2\pi}{\ln(k)} = \tan \alpha$$

In the previous steps, we converted the expression including the cotangent to an expression in terms of the tangent, since many calculators (and Excel) don't have an inverse cotangent function. Now, all we have to do is take the inverse tangent of both sides to solve for α:

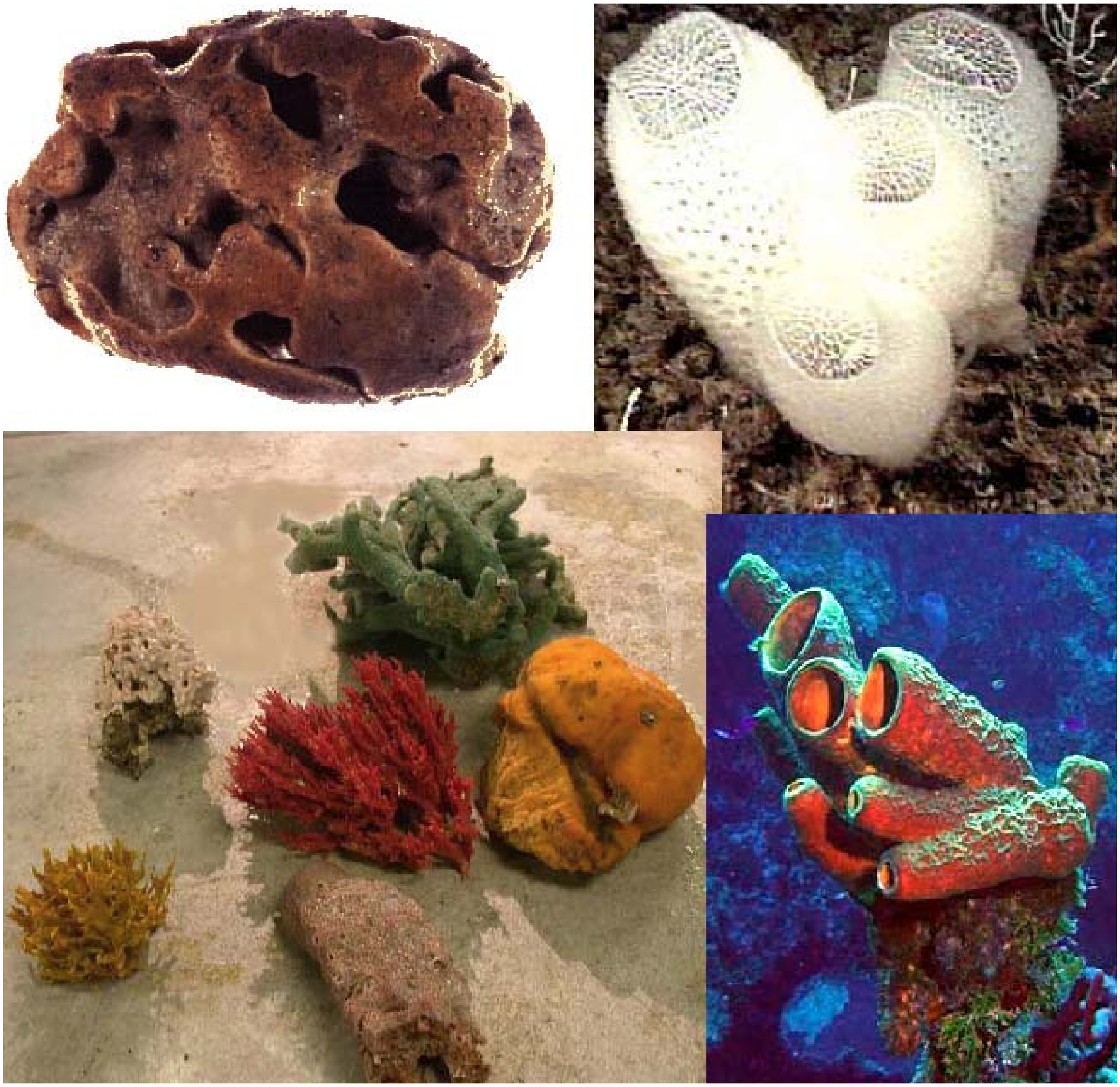
$$\alpha = \tan^{-1}(\frac{2\pi}{\ln(k)})$$

Q21. If you answered no to any of these questions, why do you think this might be the case?

The graph of a logarithmic spiral always perfectly follows the rules outlined by the parameters of the equation. However, the nautilus is a living organism, and its growth may be affected by many factors, such as temperature, food availability, changes in the community composition of its habitat, and many other possible factors or combinations of factors. Also, the nautilus's first seven chambers are formed fairly quickly during the early life of the nautilus, though later, larger chambers are added at more regular intervals. Therefore, though its growth very closely approximates a logarithmic spiral, it should be clear why it does not exactly fit the logarithmic spiral model perfectly.

STUDY SHEETS TO THE MAJOR ANIMAL PHYLA

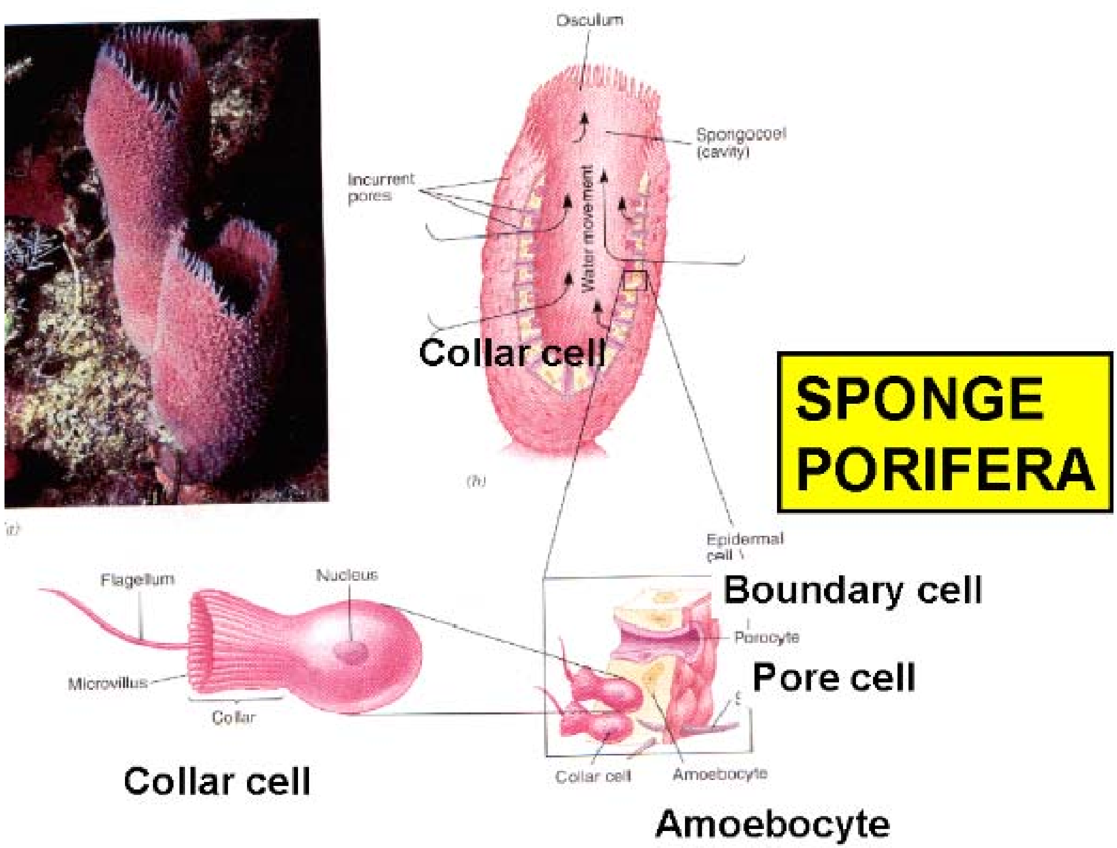
On the following pages, you are given a study sheet to each of the nine major phyla of the Kingdom Animalia. Each sheet is two-sided, with one side showing the name of a phylum, as well as several pictures of organisms in that phylum. The other side contains additional information about that phylum (such as the characteristics common to organisms within that phylum), as well as identifies the organisms in your box that are representatives of that phylum. These sheets can be used for both versions of Exercise 3, and your teacher may also wish to provide these as handouts for helping you learn the characteristics of these phyla on your own, as well.

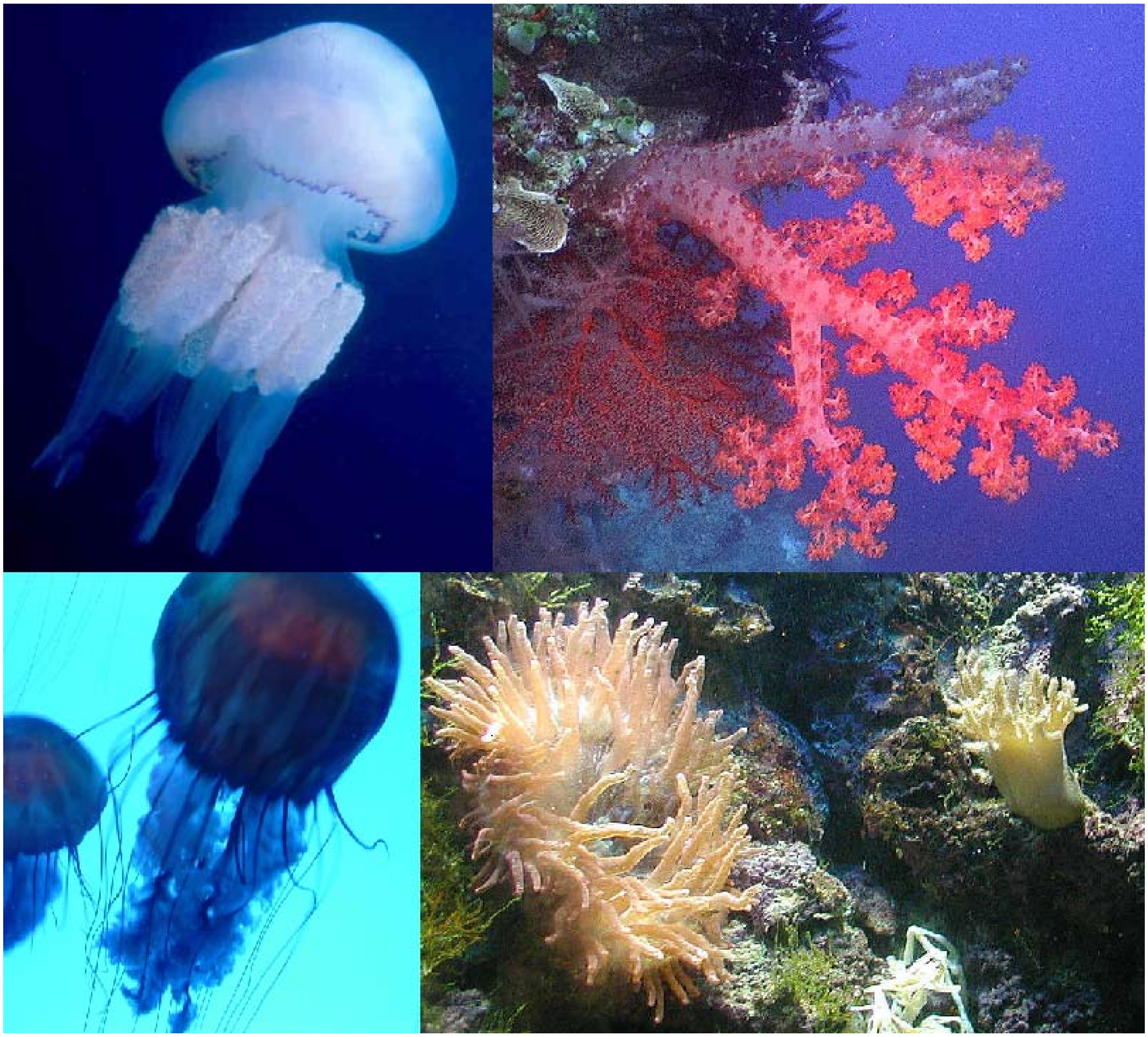


Phylum Porifera

Phylum Porifera – Sponges (Specimen 1)

Specimen #1. Sponge: Sponges were the first prominent multicellular animals. Adult sponges are **sessile** organisms, meaning that they remain anchored in one place. The larval sponge actually briefly swims in search of a place to settle down and attach, where it remains for its entire life. Sponges vary in size from just a few millimeters to over a meter in diameter. Although sponges vary in appearance, the basic body plan is a porous body with a hollow central chamber. Most sponges feed on bacteria and organic matter that they filter from the water around them, although a few species are carnivorous. Sponges lack true tissues. Instead, they have a spongy middle layer, **mesohyl** covered on either side with a thin layer of cells. There are five specialized cell types present. Boundary cells (**pinocytes**) form the thin outer protective layer of the sponge. The mesohyl is filled with a gelatinous material made mostly of collagen. Inside the mesohyl, amoeba-like cells called **amoebocytes** distribute food among the sponge's cells. There is a protective skeleton deposited within the mesohyl as well: this skeleton may be formed from calcium carbonate, silica or of a distasteful protein called **spongin**. In addition to providing structural support, the skeleton prevents other animals from consuming this sessile animal. The pores that cover the sponge are controlled by cells called **porocytes** that permit water to enter the central circulating chamber. The walls of the central chamber are lined by cells called **choanocytes**. Each has a single long flagella enclosed by a collar. The flagella create a current that brings food particles into the collars. Each collar then traps and consumes the food particles for digestion by the amoebocytes. The amoebocytes calso distribute the digested nutrients throughout the animal. The specimen in your box is actually not an entire sponge, but the spongin fiber structure produced by a sponge while it was alive.



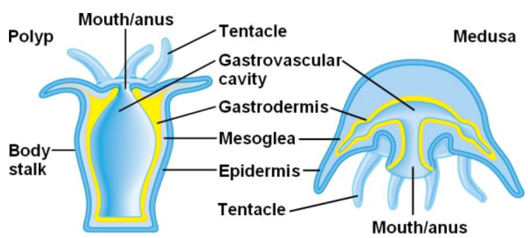


Phylum Cnidaria

Phylum Cnidaria - Jellyfishes, hydra, corals etc. (Specimens 2, 12, & 15)

The animals of the phylum **Cnidaria** (sometimes also called **Coelenterata**) were the first organisms to have tissues. The outermost layer of tissue is called the ectoderm, the middle layer of tissue is called the mesoderm, and the inner layer of tissue is called the endoderm. If you have ever been stung by a jellyfish tentacle, then you are familiar with cnidarians' stinging ectodermal cells. These cells are continuously replaced, so that a jellyfish is always ready to sting. Endoderm lines the cnidarian's digestive cavity. Mesoderm is only present as buds or globs (mesoglea) that are sandwiched between the other two layers. However, the mesoglea is very important, because it gives these animals their shape and provides jellyfish with the buoyancy they need to float in ocean currents. Cnidarians exhibit two main body forms (pictured below): the **polyp** form, which is sessile (attached to a surface with tentacles directed upwards), and the **medusa** form, which is a free-swimming, umbrella-like shape, with the tentacles directed downwards.

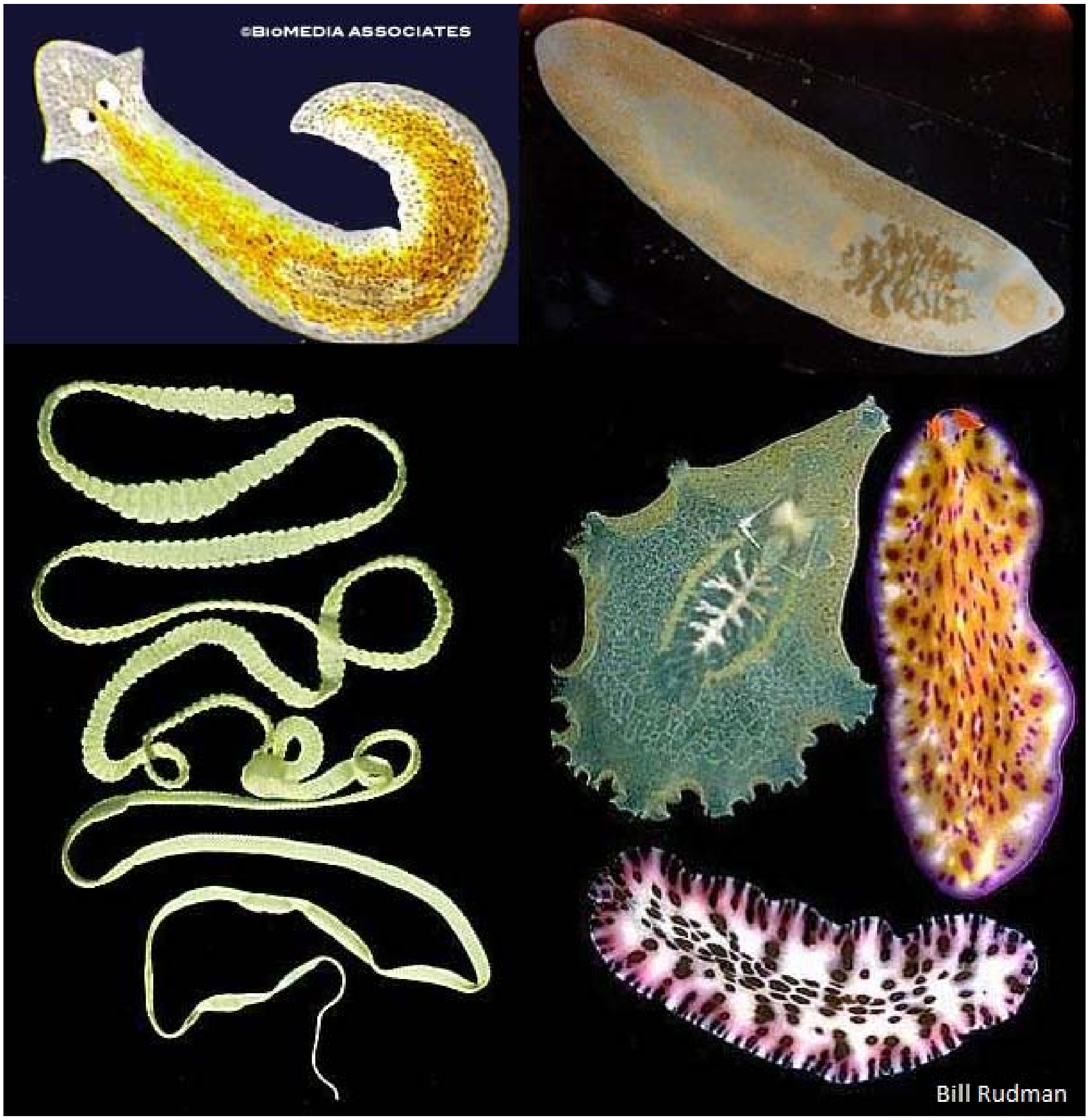
The cnidarian nervous system is a primitive nerve net that permits pulsing contractions, but no directed movement. As a result, most animals in the phylum Cnidaria are of the sessile polyp form. These animals have developed some traits to aid them with their sedentary lifestyle. Their radial symmetry allows them to interact with their entire environment without turning or moving. Their stinging cells allow them to defend themselves since they cannot move away from predators. Much of their reproduction is asexual or vegetative, so that they don't always need to find a mate to reproduce. Finally, they use their tentacles to create water currents, which carry food items directly to them.



Specimen #2. Jellyfish: The adult jellyfish has a **medusa** body shape, which is named after the Greek myth about Medusa, a monster who had snakes for hair, because of the snakelike appearance of the tentacles. The largest jellyfish has a body that is 2.5 meters in diameter with tentacles that are 36.5 meters long. Most jellyfish are marine animals that live in salt water which better supports their floating bodies. The largest species of jellyfish are located in cold waters.

Specimen #12. Hydra: Hydras are found in both marine and fresh water. They exhibit the **polyp** body form. Like other polyps, hydra may contract and shrink in size in response to adverse stimuli. The hydra gets its name from the Hydra in Greek mythology, because their waving tentacles resemble the multiple heads of the mythological beast from which they get their name.

Specimen #15. Coral: Corals are cnidarian polyps which live in colonies. This box contains the calcium carbonate exoskeleton of a coral colony. Each hole in the stone-like skeleton once contained a living individual polyp. Algae (plant-like organisms) help the coral polyps to build these skeletons. Each species of coral builds a unique skeletal shape, and many types of corals (such as star corals, fire corals, staghorn corals, finger corals, etc.) are named for the shapes formed by the exoskeletons secreted by their colonies.



Phylum Platyhelminthes

Phylum Platyhelminthes – Flatworms (Specimens 3, 15, & 18)

Flatworms, with their three clearly defined cell layers (ectoderm, endoderm, and mesoderm) and their bilateral symmetry, represent an important advance in early animal evolution. Though they do not possess a body cavity, the flatworms were the first organisms to possess organs. These organs are simple kidneys called **nephridia** and, like all organs, are composed of mesodermal tissue. In addition, the flatworms have a more advanced nervous system that features a concentration of nervous tissue in the head region. This type of organization, in which an animal has a distinct head, is known as **cephalization**. They also exhibit bilateral body symmetry with distinct right and left sides. These two traits facilitate directed movement towards and away from stimuli. The size of a flatworm is limited by the fact that it has no respiratory or circulatory system so that all gas exchange occurs via diffusion through the skin. By necessity, the flatworm's body is paper-thin to ensure that all of its cells are bathed in oxygen. Because of these limitations, many flatworms are parasitic, that is, they feed off the nutrients produced by other organisms. Two parasitic flatworms and one free-living flatworm are described below.

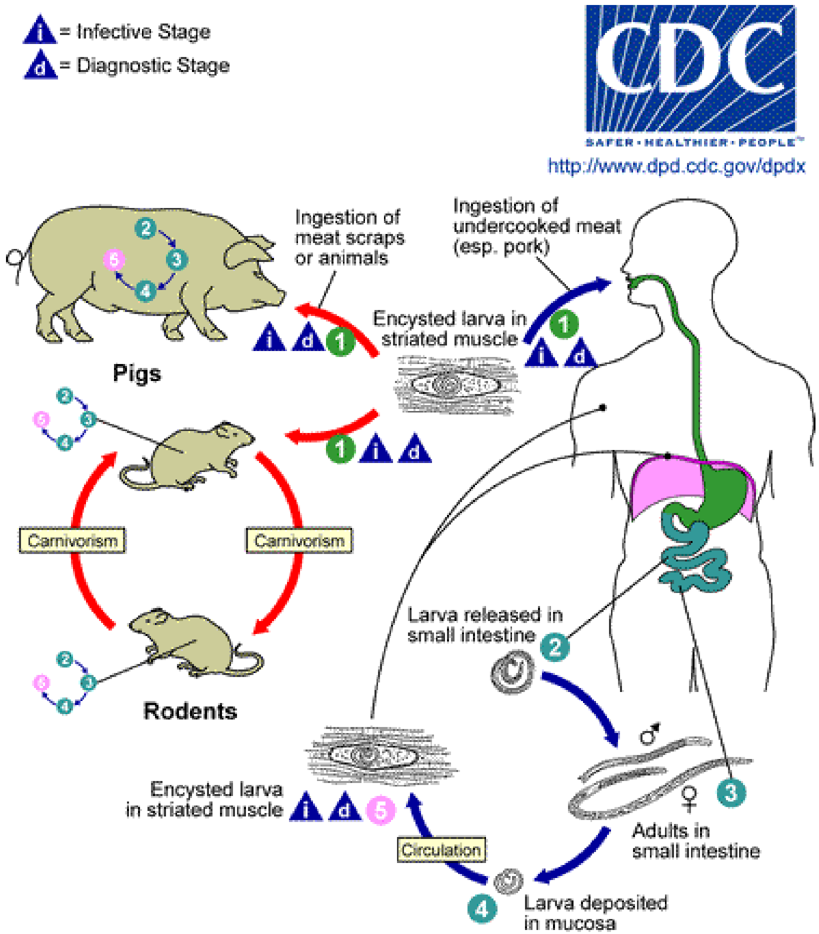
Specimen #3. Liver Fluke: The flukes are parasites. Most flukes have large sucker-like mouthparts that they use to attach themselves to their hosts. The animal pictured here is a swordfish fluke. Your specimen has a white central area that is full of reproductive organs. Parasites are often capable of producing thousands of offspring.

Specimen #15. Planaria: The planaria are free-living flatworms. That is, they search for their own food instead of depending on a host. Some planaria are carnivores (meat eaters), while others are scavengers. They creep along the bottom of ponds or under rocks in streams in search of prey (in the case of predatory species) or decaying organic material (in the case of scavengers). They are also known for their great powers of regeneration. If a planaria is split in half, both of the resulting pieces are capable of regenerating their missing parts to create a complete planaria. In this way, a single planaria can become two planaria, representing a form of asexual reproduction.

Specimen #18. Tapeworm: The specimen in your box is a tapeworm from a dog. All tapeworms spend the adult phase of their lives as parasites in the guts of their primary host animals. Tapeworms also spend other parts of their life cycle in the tissues of one or more other animals (called intermediate hosts). An adult tapeworm consists of a knoblike head, or scolex, equipped with hooks for attaching to the intestinal wall of the host, a neck region, and a series of flat, rectangular body segments, or proglottids. The chain of proglottids may reach a length of 20 ft. Each proglottid is a reproductive segment containing both male and female reproductive organs. Mature proglottids near the end of the chain contain fertilized eggs. When these segments break off the chain, they pass through the host's gut, and are expelled in the host's feces, at which point a new host can possibly be infected.

Phylum Nematoda

Phylum Nematoda – Roundworms (Specimen 4)



Specimen #4. Roundworm: The roundworms are the most abundant animal phylum in the world, with as many as 1.5 million individuals in a cubic foot of soil. They can be found in every habitat imaginable, from soil to marine and fresh water, as well as within other organisms. They are a very diverse group, ranging in size from 1 mm to several meters, with over 80,000 species known, although it can be quite difficult to distinguish among species. Approximately 20% of known roundworms are parasitic, living their lives within the body of a host (which may be either a plant or an animal), though many only live in a particular host species. The general body plan of roundworms is a slender, round-body that is tapered at both ends, and covered in a tough, resistant cuticle that protects them from dessication (drying out), from being harmed by their host's digestive fluids, or other defenses from their hosts (in the case of parasites). Roundworms are one of the phyla of **pseudocoelomate** animals. That is, they possess a body cavity surrounding their internal organs that is only lined on the outside with mesoderm. The worm that can be found encysted in pork is one of the best known roundworms, because it causes trichinosis in humans (the infection cycle of which is pictured above). However, some roundworms are beneficial because they kill agricultural pests. Roundworms are tapered at both ends, and utilize a hydrostatic skeleton to move (opposing muscles acting on a fluid-filled body). This skeleton allows them to flip-flop along. Since the roundworm has such an inefficient method of locomotion, it is not surprising that many are parasites that live inside and rely on other organisms for food. Your specimen is a dog roundworm which steals nutrients from the digestive tracts of dogs.

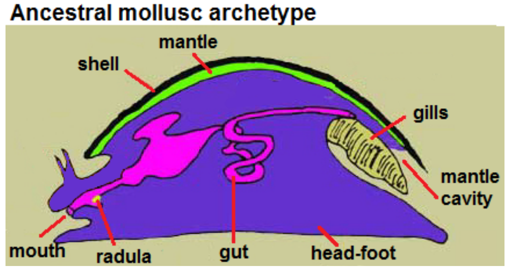
Phylum Mollusca

Phylum Mollusca – Molluscs (Specimens 5, 11, & 21)

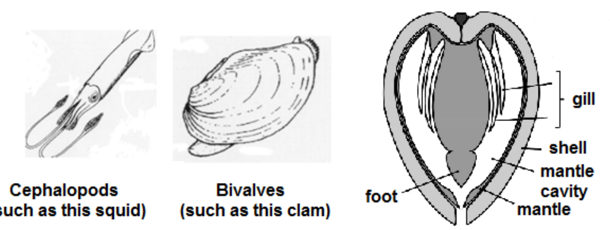
Mollusc means “soft”, which refers to the soft body of all of these organisms. However, most molluscs also have a shell, although in the cephalopods (including squid and octopi), it is greatly reduced and internal (though some species of octopus have lost the internal shell entirely. Like other higher animals, at some phase of their development, molluscs have bilateral symmetry. This very successful group was even more dominant in the seas before the development of the fishes.

- Look at the archetype below. This is a schematic of what is considered to be the generalized ancestor of the modern groups of molluscs. Two features are present: a muscular head-foot, and a mantle cavity where gas is exchanged and waste is excreted. Modern forms emphasize either the the mantle cavity, as do the bivalves (such as clams) and cephalopods (squid, octopi, etc.) or the muscular head-foot, as do the gastropods (which include snails, chitons, and relatives). There are about 75,000 species in marine, freshwater, and terrestrial forms.

Ancestral mollusc archetype



Modern molluscs that emphasize the mantle cavity

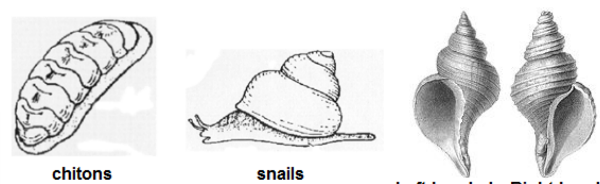


Cephalopods (such as this squid)

Bivalves (such as this clam)

Cross section of a clam showing expanded mantle cavity

Modern molluscs that emphasize the head-foot



chitons

snails (and other gastropods)

Left-handed spiral

Right-handed spiral

Specimen #5. Clam: Clams belong to the mollusc class Bivalvia (“two valves”), so named because they possess shells consisting of two separate valves. Bivalves utilize their gills for filter feeding. In other molluscs, the gills are reduced, and are only used for gas exchange. This box contains only one valve of a clam’s shell. The two halves would have been attached at the narrow dorsal end of this shell. The mouth and gills would have extended ventrally towards the shell edge, which would have opened to expose them during feeding.

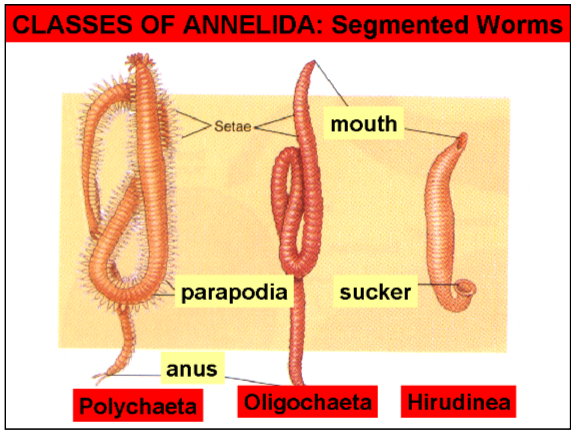
Specimen #11. Cephalopod: Organisms in the mollusc class Cephalopoda, such as the octopus and squid, do not have an external shell. Instead, they have a shell that is greatly reduced (or absent in some species of octopus) and internal. An exception is the nautilus, which has an external shell. The octopus has eight arms of equal size lined with two rows of suckers, which they use to hold on to their prey. Squid have eight arms also lined with suckers and two longer tentacles. Cephalopods have keen eyesight and well-developed brains, which make them efficient predators. They can escape from their own predators using a kind of jet propulsion by forcing water out of the mantle cavity.

Specimen #21. Snail: Members of the class Gastropoda, which includes snails and their relatives, have a spiral shell with a single opening. The spiral increases in diameter as it progresses towards the open end. Most shells have a right-handed spiral. You can tell if your shell is left or right-handed by holding the shell so that its opening faces you and its spiral points up. What is the direction of the spiral of your specimen? Does the snail shell have symmetry? No, in fact the snail shell is asymmetrical, and internally, so is the snail. This asymmetry is the result of a developmental process called torsion, in which the snail’s organ system is twisted, some of its organs are lost, and the spiral shell is created. Why does the snail go through torsion? The snail may have developed torsion as a defense against predators. Torsion allows the snail to fully retract its head into its shell, thus improving its chances of surviving an attack. The shells of many molluscs, including snails, follow a mathematical formula known as a logarithmic spiral. If you wish, consult the book for this unit for an additional exercise on logarithmic spirals.

Phylum Annelida

Phylum Annelida – Segmented Worms (Specimens 6, 13, & 17)

An annelid worm has a flexible body that is divided into many identical segments. Some of the ancestral segmented worms had as many as 200 segments. The same muscles, nerves, and even organs are present in each segment. This design increases the efficiency of their hydrostatic skeleton, thereby allowing them to better direct their movements. Many annelids also possess setae (also called chaetae), which are small bristle-like structures on their segments. These improvements are useful in the burrowing habits of many annelid worms.

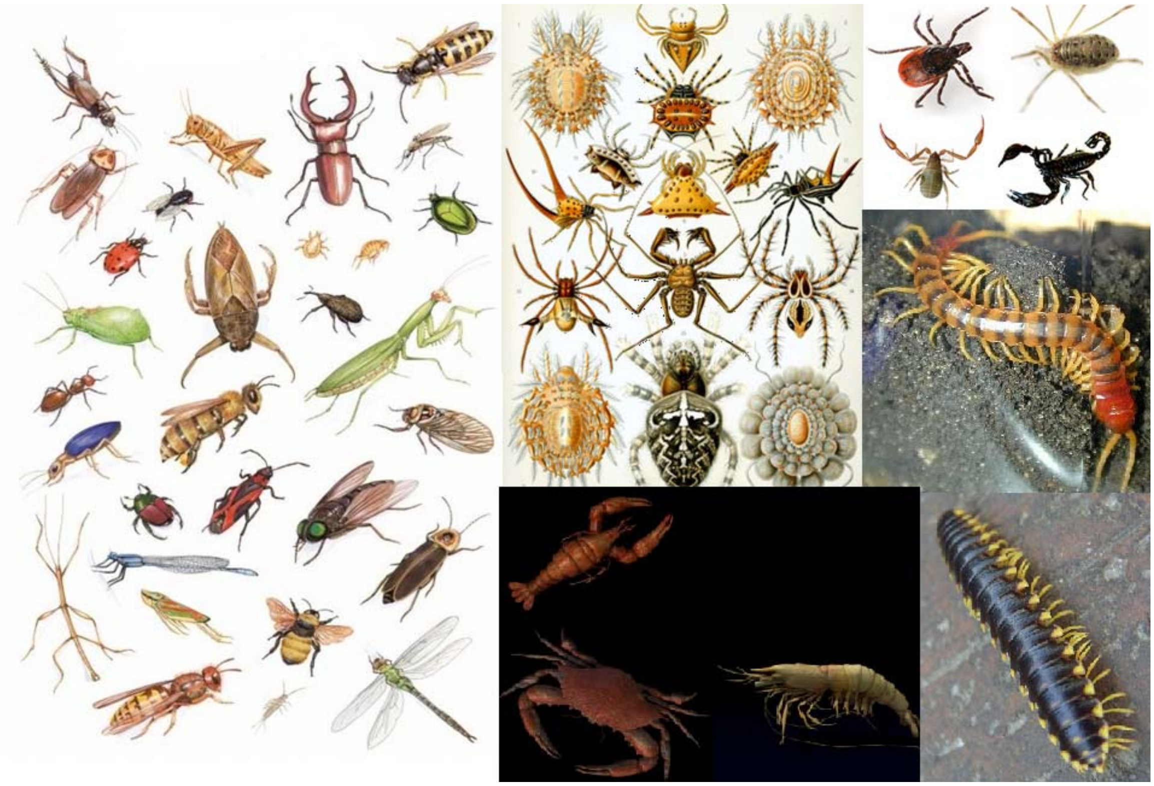


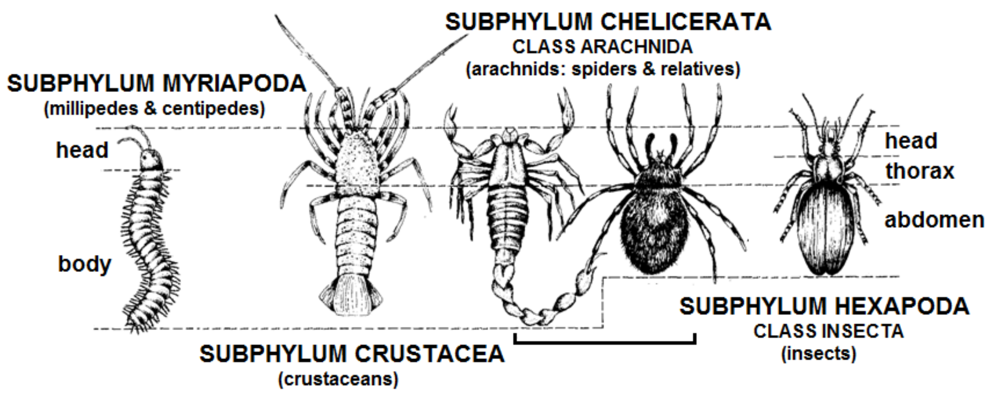
Traditionally, the annelids have been classified into three separate classes: the **Polychaeta** ("polychaete" means "many bristles"), which are a large group of mostly marine worms (though there are some freshwater and terrestrial species), the **Oligochaeta** ("oligochaete" means "few bristles"), which includes the familiar earthworm, and the **Hirudinea** (leeches), which lack setae altogether. Currently, however, the classification of annelids into lower taxa (groups) is a topic of much debate.

Specimen #6. Bristle worm (Class Polychaeta): A bristle worm is a member of the marine worm class Polychaeta. Each segment of the worm has a pair of fleshy limbs called parapodia or 'almost feet' that help the worm to crawl along or burrow into the seafloor. The Polychaeta can also swim in an undulating fashion. Most polychaetes are predators.

Specimen #13. Leech (Class Hirudinea): Most leeches are parasites that feed on the blood of vertebrates. They usually have a sucker at the mouth and sometimes at the tail which they use to attach to their host during feeding. The leech that fishermen use as bait is a scavenger that lives in streams and ponds, not a parasite. It has suckers at both ends of its body which it uses to attach itself to rocks. There are some species of leeches that are neither parasites nor scavengers, but predators on small invertebrates. Leeches were once used to bleed humans when they were sick (this was thought to rid them of "bad blood"). Few species of leeches are parasitic on humans.

Specimen #17. Earthworm (Class Oligochaeta): The class Oligochaeta makes up around half of all annelid worms, and includes terrestrial, freshwater, and marine species. Compared to polychaetes, they have relatively few bristles (the Greek prefix "*oligo*-" means "*few*"). Earthworms move through dirt through muscular contractions of their bodies, using their setae/chaetae to help anchor and move them through the soil. As they move through the earth, air passes through their tunnels, providing important gases to vegetation. By digestively breaking down the dead organic matter that they eat, earthworms also help make valuable nutrients more readily available in the soil, greatly enhancing soil quality where they live.

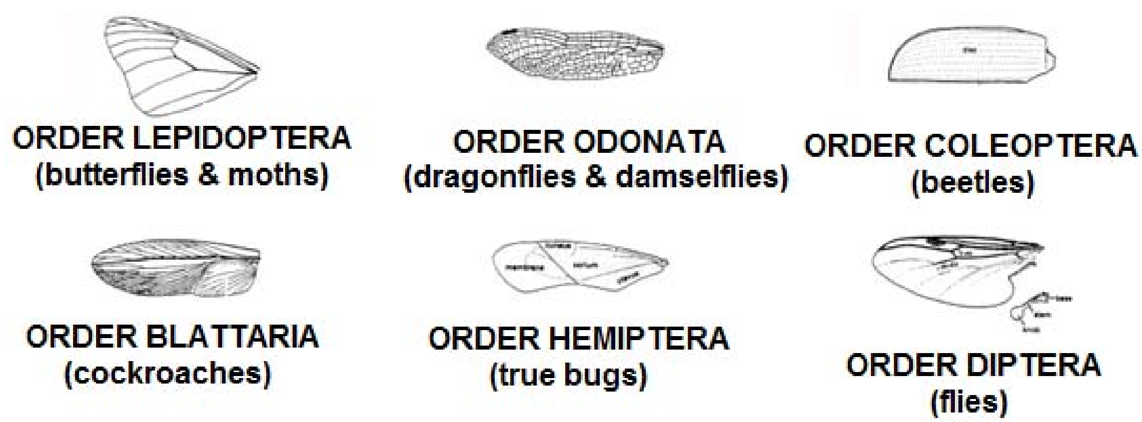




Phylum Arthropoda

Phylum Arthropoda – Arthropods (Specimens 7, 10, 16, & 22)

The arthropods are specialized, segmented animals. They have fewer segments than the annelids, and their segments are not identical, but rather specialized to perform specific functions. For instance, some of their segments are mouthparts, and each pair of their legs differs in shape and function. As a result, their movement is more efficient and diversified than that of the annelids. They also have a hard external skeleton for the legs to push against. This eliminates the need for a hydrostatic skeleton. Because the arthropods use a lever system to propel themselves, they are called joint-legged. However, the hard exoskeleton does not permit gas exchange through the body surface. Arthropods have no lungs, and in most groups, gas exchange between the tubes and tissue is accomplished via passive diffusion. The arthropods are the most diverse phylum of animals, making up over half of all currently described species on earth! There are four subphyla within the Arthropoda: Myriapoda (millipedes and centipedes), Crustacea (crabs, shrimp, lobsters, etc.), Chelicerata (which includes arachnids, such as spiders and their relatives), and Hexapoda, which includes the insects. Of all the arthropods, the insects are the most diverse. The insect's wings are responsible for this success, as they grant the distinct advantage of allowing insects to travel greater distances to find suitable feeding patches, as well as mates.



Specimen #7. Subphylum Crustacea: Members of the subphylum Crustacea are primarily aquatic, though some (including some isopods, or pillbugs, which you may know as "roly polies") are terrestrial. Your specimen is either a krill, which is a small, shrimp-like creature, which play a key role in Antarctic food webs, a crab, or a terrestrial isopod. Note the jointed legs, claws, and hard exoskeleton, which are all characteristic of the arthropods.

Specimen #10. Subphylum Hexapoda, Class Insecta: Insects are the most diverse group of animals, with over a million recognized species. Most adult insects have wings. Examine the wing types pictured above. Do you think the insect in your box belongs to one of these insect orders? Scientists also use legs and mouthparts in insect identification.

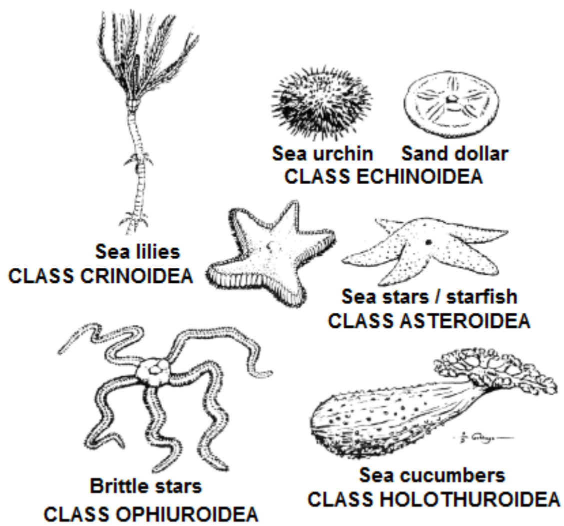
Specimen #16. Subphylum Chelicerata, Class Arachnida: Arachnids have four pairs of walking legs, an accessory pair of pincher-like appendages in the front that have fangs and are used in subduing prey, and two main body segments. Your specimen may be a spider (order Aranea), a harvestman (order Opiliones, which you may know as a "daddy long-legs," which look like spiders, but technically aren't), a scorpion (order Scorpiones), a tick (order Ixodida), or perhaps a mite (order Acarina). Most arachnids rely on external digestion, and can only take liquid meals, which they suck out of their prey after injecting digestive enzymes, though some harvestmen and mites eat some solids. Ticks and many mites are parasites, living on the blood of animal hosts, while some mites suck juices out of plant hosts.

Specimen #22. Subphylum Myriapoda: Both centipedes (Class Chilopoda) and millipedes (Class Diplopoda) are in the subphylum Myriapoda, which means "many feet". "Centipede" means "100 legs," and "millipede" means "1000 legs," though neither group has as many legs as their names imply. Centipedes have one pair of legs per body segment, while millipedes have two pairs of legs per segment. Look closely at your specimen. Is it a centipede or a millipede? Centipedes are predators, and subdue prey specialized mouthparts, which are actually modified legs tipped with venomous claws that paralyze their prey. Millipedes are scavengers that typically feed on decaying leaves, other vegetable matter, and fungi. Though they do not have the capability to inject venom, millipedes can protect themselves by producing compounds that are poisonous or distasteful to predators that might try to eat them.

Phylum Echinodermata

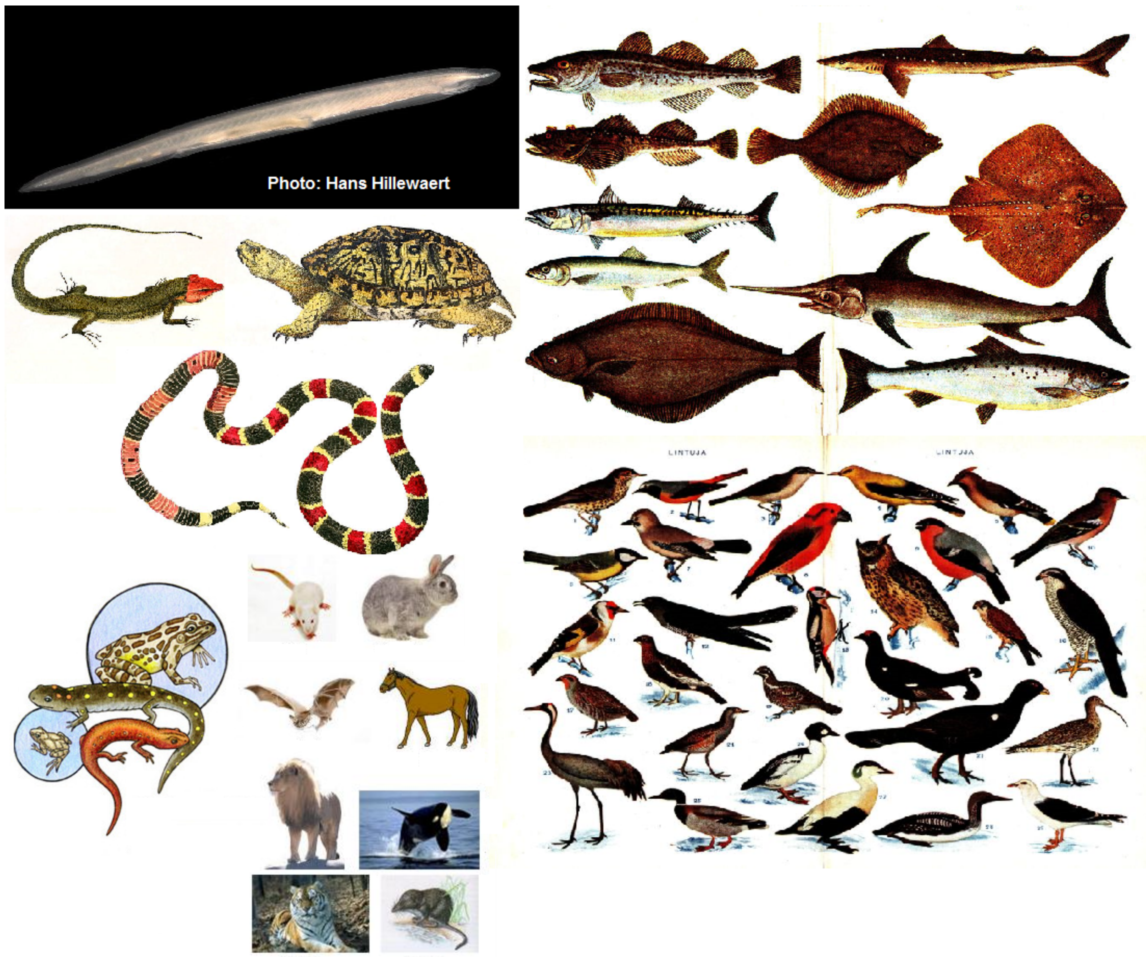
Phylum Echinodermata – Echinoderms (Specimens 8 & 20)

The echinoderms are interesting animals because they have complex body plans, but externally they look more like the primitive sponges than the chordates, their closest relatives. Their larvae have bilateral symmetry, like all of the advanced animal groups. However, the adults have radial body symmetry, reflecting their sedentary lifestyle. The primitive crinoids remain anchored in place like sponges, while the starfish, the sea cucumbers, and the sea urchins have hydrostatic skeletons which enable them to move slowly about the ocean floor (water forced into tube feet by muscular contraction). Echinoderms are so named because of the bony plates they possess in their exoskeletons ("echino-" means "spiny", and "-derm" means "skin"). All the members of this animal group are marine.



Specimen #8. Class Asteroidea: Starfish: True starfish are distinguished from the brittle stars (class Ophiuroidea) in that their arms are not sharply demarcated from their central bodies. They also move only through tube feet rather than by wiggling their arms (as do the brittle stars). The starfish are the largest of all of the predatory echinoderm classes. They use their tube feet (which can be seen extending from the grooves on the underside of the arms above) to pry open clams, which are their preferred food items. Some starfish can extrude part of their stomachs through their mouths in order to digest food outside of the body.

Specimen #20. Class Echinoidea: Sea Urchins: Sea urchins and sand dollars (class Echinoidea) do not have arms, but only a central disk. Urchins are browsers. The sea urchin uses a conveyor belt-like apparatus called a radula to scrape algae off rocks in shallow marine waters or on coral reefs. The specimen you have lacks the protective spines shown in the picture because it is only the calcareous skeleton, or test, of a sea urchin. The test clearly exhibits the radial body symmetry of the echinoderm. In the living specimen, a spine would extend out of each pimple on the test.



Phylum Chordata

Phylum Chordata (Specimens 9, 19, & 23)

At some stage in their life cycle, all of the chordates have a dorsal hollow nerve cord (dorsal means located at the upper side of an animal that typically move with their bodies in a horizontal orientation, or the back side of organisms that walk upright), a flexible skeletal rod called a notochord, gill slits, and a post-anal tail (a tail which extends past the anus). The phylum Chordata is divided into three main subphyla: subphylum Urochordata (the sea squirts and tunicates), subphylum Cephalochordata (the cephalochordates, including lancelets, sometimes called amphioxus, which means "pointed at both ends"), and the most familiar subphylum, Vertebrata (animals with vertebrae, or a "backbone").

Specimen #9. Lancelet (subphylum Cephalochordata): While members of the subphylum Cephalochordata look like fish, they are actually advanced burrowing animals that have a notochord in their adult stage. The lancelet, or amphioxus (which means "pointed at both ends"), is a filter-feeder that inhabits shallow marine waters where it buries itself in the sea floor. It uses its notochord to aid in burrowing. The gills, which it uses to breathe, are also used to collect small food particles from the water. The cephalochordates were traditionally regarded as being the closest non-vertebrate relatives of vertebrates, but the current most widely-accepted notion, based on newer evidence, is that the tunicates (subphylum Urochordata) are more closely related to the vertebrates than the cephalochordates.

Specimen #19. Fish (subphylum Vertebrata): Fish are representatives of the vertebrates. Vertebrates are chordates that protect their hollow dorsal nerve cord with ectodermal material (bones). These bones appear as a segmented skeleton. In more advanced vertebrates, pelvic & pectoral girdles hang from the vertebral column where it provides support to the limbs. In most vertebrates, the notochord is only present during embryonic development. This subphylum of the chordates is extremely successful because they are able to protect their nerve cords, and because they have many other skeletal adaptations that help them survive. Fish have two additional features that have served them well. First, they have lateral (side) fins that allow them to swim more quickly and turn more sharply than the early vertebrates or the swimming, non-vertebrate chordates (such as the lancelet). Second, fish can breathe while they are stationary by moving a protective flap (operculum) over their gills. The fish specimen in your box is a member of the class Osteichthyes, or the bony fish. Sharks, skates, rays, and their relatives, are members of the class Chondrichthyes, whose skeletons are made up of cartilage instead of bone. Below is a list of all of the traditional classes of vertebrates, and the organisms they contain.

Class Agnatha – jawless fishes
Class Chondrichthyes – cartilaginous fishes (sharks and relatives)
Class Osteichthyes – bony fishes
Class Amphibia – amphibians (frogs, toads, salamanders, and caecilians)
Class Reptilia – reptiles (lizards, snakes, turtles and tortoises, crocodilians)
Class Aves – birds
Class Mammalia – mammals

Many scientists use a slightly different classification system, based on the fact that these "traditional" groupings do not all contain all of the descendants of a common ancestor. For example, if we wanted to use groupings that consisted of all of the descendants of a particular ancestor, the birds should be grouped in with the reptiles!

Specimen #23. Sea squirt (subphylum Urochordata): Sea squirts (also called tunicates) start their lives looking like tiny tadpole-like larvae. They swim around until they find a suitable spot to live, then attach themselves to a substrate, where they mature and transform into a simple, tubelike form similar in appearance to sponges. Adults are filter feeders, who take water (containing their plankton food) into an incurrent siphon, and pass waste and water out of an excurrent siphon. Many tunicates produce compounds that are used in the treatment of various types of cancer.

Guide to Gastropod Shells in Unit 6: Animal Kingdom

Snails in the genus *Nassarius* are saltwater snails that typically live in shallow waters. They are scavengers that feed on films of algae and detritus (decaying organic material). They are often seen in marine aquariums, where they help keep the glass clean.

Striped nerite snails are in the family Neritidae. These snails are found all over the world, but are most common in tropical areas. They can live in marine and freshwater habitats, and are most often found in intertidal areas, where they are often exposed to the sun. The majority of species in this family are herbivores that graze on algae, but some also have carnivorous diets, and eat larvae of flies on the roots of mangrove trees.

Species in the genus *Strombus* (the true conchs) live on muddy and sandy bottoms in marine habitats, and range from shallow waters to depths of over 160 feet. They are mostly herbivores, feeding on algae and marine plants. An unusual "leaping" motion is common in this genus, in which the conch digs the pointed end of their operculum (shell door) into the sand or mud, then thrusts its body forward with its muscular foot.

The lettered olive (*Oliva sayana*) is a species native to North America. This species typically lives near shore, on flat sandy areas, where they capture bivalves and small crustaceans for their carnivorous diet. This species is the state shell of South Carolina.

Haitian Tree Snails (*Liguus virgineus*, sometimes also called candy cane snails) live in trees, where they feed on fungi, algae, and lichens that grow on their host trees' bark. During dry seasons, they glue themselves to the bark of a tree and seal their shells with the slimy mucus produced by their bodies, and aestivate (pronounced ESS-tiv-ate), which is a term used to describe a period of summer dormancy (similar to hibernation in winter). When the rainy season comes again, the snails again become active.

Sundial snails (in the family Architectonicidae) typically live in warm, shallow waters, on sandy bottoms in marine habitats. They are found along the coasts of North and South America, as well as in the Pacific. Cnidarians, such as sea anemones and corals, are the preferred food of these predatory snails, which can be pests in marine aquaria.

Moon snails (in the family Naticidae) are a diverse group of approximately 300 species, which can be found in marine waters worldwide, even in the Arctic! They are highly predatory, and actively pursue bivalves, as well as other snails, including their own kind!

Land snails and slugs (formerly classified into the order Pulmonata, which is no longer considered a valid group) breathe with a single lung. Several species of land snails, such as the one in your box, are polymorphic, occurring in many different forms, or morphs. Some species vary widely in color, ranging from almost white to yellow, pink, green, and brown. They may also display great variation in the number and intensity of bands on their shells. Different morphs are more common in different types of habitats. The yellow form is most commonly found in grasslands, where they are more well-camouflaged from their bird predators. Most land snails and slugs are herbivores that eat grass, leaves, algae, and fruits.

SUGGESTED READING

Grades K-3

First Animal Encyclopedia - DK Publishing
The Little Animal Encyclopedia - Jarn Farndon & Jon Kirkwood
Wild Animals Coloring Book - John Green
The Kingfisher First Encyclopedia of Animals - Kingfisher Publishing
A Walk in the Rainforest - Kristin Joy Pratt
Disney Learning: Wonderful World of Animals - Dr. Donald Moore
National Geographic Animal Encyclopedia - National Geographic Society
The Complete Book of Animals - School Specialty Publishing

Grades 4-7

Animals and Habitats of the United States - Jeff Corwin
DK Nature Encyclopedia - DK Publishing
What's That Bug?: Everyday Insects and their Really Cool Cousins – Nan Froman & Julian Mulock (Illustrator)
Variation and Classification – Ann Fullick
Bats, Bugs, and Biodiversity: Adventures in the Amazonian Rain Forest - Susan E. Goodman & Michael J. Doolittle
Strange New Species: Astonishing Discoveries of Life on Earth - Elin Kelsey
Pet Bugs: A Kid's Guide to Catching and Keeping Touchable Insects - Sally Kneidel
More Pet Bugs: A Kid's Guide to Catching and Keeping Insects and Other Small Creatures - Sally Kneidel
The Encyclopedia of Awesome Animals - Claire Llewellyn
Extremely Weird Micro Monsters - Sarah Lovett
National Geographic Encyclopedia of Animals - Karen McGhee & George McKay
The Visual Dictionary of Animals - Martyn Page (Editor), Clare Shedden (Author), Richard Walker, Andrew Nash
Sponges, Jellyfish, & Other Simple Animals – Steve Parker
Tree of Life: The Incredible Biodiversity of Life on Earth - Rochelle Strauss & Margot Thompson (Illustrator)
One Million Things: Animal Life - Richard Walker
The Simon & Schuster Encyclopedia of Animals: A Visual Who's Who of the World's Creatures - Philip Whitfield

Grades 7+

Synoptic key to the phyla, classes, and orders of animals; with particular reference to fresh-water and terrestrial forms of the moist temperate region in North America - Warder Clyde Allee
Animal: The Definitive Visual Guide to the World's Wildlife - David Burnie (Author) & Don E. Wilson (Editor)
On the Origin of Phyla - James W. Valentine
Sustaining Life: How Human Health Depends on Biodiversity - Eric Chivian & Aaron Bernstein (Editors)
Assembling the Tree of Life - Joel Cracraft & Michael J. Donoghue (Editors)

One Kingdom: Our Lives with Animals - Deborah Noyes

All Ages

The Beauty of the Beast: Poems from the Animal Kingdom - Jack Prelutsky, Meilo So (Illustrator)

Scientific Journal Articles (included on Teacher CD!)

Aguinaldo, A.M.A., J.M. Turbeville, L.S. Linford, M.C. Rivera, J.R. Garey, R.A. Raff, & J.A. Lake. 1997. Evidence for a clade of nematodes, arthropods and other moulting animals. *Nature* 387:489-493.

Dunn, C.W., A. Hejnol, D.Q. Matus, K. Pang, W.E. Browne, S.A. Smith, E. Seaver, G.W. Rouse, M. Obst, G.D. Edgecombe, M.V. Sorensen, S.H.D. Haddock, A. Schmidt-Rhaesa, A. Okusu, R.M. Kristensen, W.C. Wheeler, M.Q. Martindale, & G. Giribet. 2008. Broad phylogenomic sampling improves resolution of the animal tree of life. *Nature* 452:745-750.

Goodfriend G. A. 1986. Variation in land-snail shell form and size and its causes – a Review. *Systematic Zoology* 35: 204-223.

Hoso, M., T. Asami, and M. Hori. Right-handed snakes: convergent evolution of asymmetry for functional specialization.

Kaiser, A., C.J. Klok, J.J. Socha, W. Lee, M.C. Quinlan, & J.F. Harrison. 2007. Increase in tracheal investment with beetle size supports hypothesis of oxygen limitation on insect gigantism. Proceedings of the National Academy of Sciences 104(32): 13198-19203.

Raup, D.M. 1961. The geometry of coiling in gastropods. Proceedings of the National Academy of Sciences of the United States of America 47(4):602-609.

LINKS

Animal Phyla – A page by Wayne Armstrong which provides a great overview of similarities and differences among the nine major animal phyla.

http://waynesword.palomar.edu/trnov01.htm

Animals, Animal Pictures, Wild Animal Facts – National Geographic's page on animal diversity. Contains lots of interesting information for all ages.

http://animals.nationalgeographic.com/animals/

Archerd Shell Collection – A web-based tour of the Archerd Shell Collection at Washington State University Tri-Cities Natural History Museum. Provides great info on the main classes of mollusc shells, shell development, torsion in gastropods, and more!

http://shells.tricity.wsu.edu/ArcherdShellCollection/ShellCollection.html

Basic Venn Diagrams – Information on Venn diagrams as a graphic organizational tool.

http://www.graphic.org/venbas.html

Bilateral (left/right) symmetry – Great page from the University of California Berkeley that effectively illustrates the concept of animal symmetry.

http://evolution.berkeley.edu/evolibrary/article/_0_0/arthropods_04

Biology4Kids.com – A great site with information on invertebrate and vertebrate animals, as well as organisms from the other kingdoms of life. The subpages most appropriate for this unit are those for the invertebrates and vertebrates:

http://www.biology4kids.com/files/invert_main.html

http://www.biology4kids.com/files/vert_main.html

Class Gastropoda (Snails and Slugs) - Biodiversity of Great Smoky Mountains National Park - a great website about the gastropod diversity found in our own home state, with lots of information on land snail importance, life histories, anatomy, and identification!

http://www.dlia.org/atbi/species/Animalia/Mollusca/Gastropoda/index.shtml

Create A Graph – Nice interactive page from the National Center for Education Statistics which allows students to create customizable graphs of many types online.

http://nces.ed.gov/nceskids/createagraph/

General Overview of Animal Phyla – Page from the Department of Biology at Bellarmine University. providing clickable pictures of animal phyla representatives (with each phylum page containing lots of additional informational links), as well as good definitions of various terminology.

http://cas.bellarmine.edu/tietjen/images/general_overview_of_animal_phyla.htm

GraphJam.com – An amusing (and sometimes irreverent) website using various types of graphs in a humorous manner. Even includes an interactive graph creator for students to produce their own funny graphs of many different types (brought to you by the same folks that started the LOLcat craze!)

http://graphjam.com/

Kingdoms of Life – Another page by Wayne Armstrong at Palomar Community College. Provides a great broad overview of biodiversity and higher level taxonomy. (Note: This page lists Bacteria and Archaea as in the same kingdom, Monera, but distinguishes the two at the domain level, which is another common convention among biologists.)

http://waynesword.palomar.edu/trfeb98.htm

OLogy: Biodiversity – Everything Counts! – A great page with lots of activities about biodiversity for all ages, presented by the American Museum of Natural History.

http://www.amnh.org/ology/index.php?channel=biodiversity

OLogy: Tree of Life Cladogram – From the American Museum of Natural History, this site presents a cladogram of several major groups of organisms, as well as gives younger students a tutorial on how to read/interpret cladograms.

http://www.amnh.org/ology/features/treeoflife/pages/cladogram.php

Tree of Life Web Project – "Provides information about biodiversity, the characteristics of different groups of organisms, and their evolutionary history."

http://www.tolweb.org/tree/

UCMP Web Lift to Taxa – Great page with numerous links to various groups of organisms, presented by the University of California Museum of Paleontology

http://www.ucmp.berkeley.edu/help/taxaform.html

Understanding Phylogenies – Excellent page from the University of California Berkeley, which provides an excellent tutorial on phylogenies, including how to read/interpret them, as well as how they are constructed.

http://evolution.berkeley.edu/evolibrary/article/0_0_0/evo_05