

# ***Biology in a Box***

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# UNIT 8: EVERYTHING VARIES



# Homepage Unit 8: Everything Varies

Click on underlined text to go to information and exercises!

## Materials List

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### Exercise 2: Leaf Match

### Exercise 3: Using Mathematics to Describe a Population

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### Exercise 8: Mechanisms Underlying Variation


### Guide to Leaves in Unit 8

### Guide to Shells in Unit 8

### Guide to Snail Shells in Unit 8, Exercise 8

## SUGGESTED READING

## LINKS

Clicking the  icon on other slides will bring you back to this page!

## Unit 8: Everything Varies – Materials List

- ☐ Container A, which contains
  - ☐ 35 unique Leaves
- ☐ Container B, which contains
  - ☐ 30 leaves of species A
  - ☐ 30 leaves of species B
- ☐ Container C, which contains
  - ☐ 30 mollusk shells with red dot on each
- ☐ Container D, which contains
  - ☐ 30 mollusk shells with blue dot on each
- ☐ Container E, which contains
  - ☐ A “mystery shell”
- ☐ Bag containing
  - ☐ 6 individual bags, each with
    - ☐ 10 assorted snail shells
- ☐ 6 rulers
- ☐ 6 protractors
- ☐ 1 container with a cloth bag of beads of 2 colors



# Introduction

- ❑ There are approximately 1.8 million *named* species.
- ❑ However, scientists estimate that the Earth may actually be home to over 10 million species.
- ❑ Why are there so many different kinds of living things? Or, to put it another way, why is there so much variety?
- ❑ Earth has a lot of geological variation, that is, it has many different types of physical structures.
- ❑ Also, the Earth's shape and the way it orbits the sun create variation in Earth's climate.
- ❑ Climatic and geographical variability create a variety of habitats, or homes, in which organisms can live.
- ❑ Organisms vary because everything else varies, and each species has adapted traits that help it to survive in the place where it lives.
- ❑ In this series of exercises, you will explore the variation of life by examining leaves and seashells.

## **In this unit, the student will...**

- ☐ test their memory and powers of observation in learning to identify leaves and shells.
- ☐ learn how to quantify variation present in samples, as well as how to compare variation between samples.
- ☐ group items/organisms based on similarities.
- ☐ learn about how taxonomists divide organisms into species, and about various species concepts.
- ☐ learn about the sources of variation in various organisms, as well as the importance of variation in various contexts.

## **Exercise 1: Recognizing Individuals as Unique**

- ☐ Locate container A, which holds 35 laminated leaves. Each leaf has a unique number on its back.
- ☐ Select one leaf from this batch. Carefully examine the upper surface of this leaf (the side without the number) for a few minutes and try to commit its appearance to memory.
- ☐ After studying the leaf, turn it over and write down the number on its back.
- ☐ Return the leaves to the container.
- ☐ The teacher will now mix up the leaves, and spread them leaves face up on a table.
- ☐ Each student should now try to find his or her 'special leaf' without looking at the number on its back.
- ☐ The teacher will check the number on your leaf to see if it matches the number from the leaf you originally examined.
- ☐ The teacher should keep a tally of the number of students that were successful in finding their leaves.

## Exercise 1: Recognizing Individuals as Unique

- ❑ What was the class success rate?
- ❑ Rate can be expressed in different ways. It can be expressed as a fraction, a decimal, or a percent. For this exercise, you will find the group success rate using a percent. How do you do that?
- ❑ **Example:** If 10 individuals out of 30 found their leaves, the success rate can be expressed as a fraction (ratio), which can then be converted to a decimal, and then converted to a percent.

$$\frac{\text{number correct}}{\text{total number}} = \frac{10}{30} = 10 \div 30 = 0.333\dots$$

- ❑ Once you have found your decimal by dividing the numerator by the denominator, you will then multiply the decimal number by 100 to find your percent.

$$\text{class success rate} = \frac{\# \text{ of students who found their leaf}}{\# \text{ of students in the class}} \times 100$$

- ❑ **Example:**  $0.333 \times 100 = 33.3\%$ , which means the rate of success in finding the correct leaves is 33.3%.



## Exercise 1: Recognizing Individuals as Unique

- ❑ Next you will make a table to summarize the outcome of this game. This table will help you to decide which traits are the best ones to use when identifying leaves.
- ❑ Discuss the characteristics that each student used to remember their leaves.
- ❑ Make a table like the one that follows. If a student used more than one characteristic, use the characteristic that they looked for first when they went up to the table.

| <b>Trait</b>     | <b>Absolute Frequency</b> | <b>Relative Frequency</b> | <b>Number of Successes</b> | <b>Trait Success Rate</b> |
|------------------|---------------------------|---------------------------|----------------------------|---------------------------|
| <b>Shape</b>     |                           |                           |                            |                           |
| <b>Size</b>      |                           |                           |                            |                           |
| <b>Color</b>     |                           |                           |                            |                           |
| <b>Leaf Edge</b> |                           |                           |                            |                           |
| <b>Damage</b>    |                           |                           |                            |                           |
| <b>Venation</b>  |                           |                           |                            |                           |

## Exercise 1: Recognizing Individuals as Unique

- ❑ In the table you are asked to record the absolute and relative frequencies with which each trait was used in leaf identification.
- ❑ The **absolute frequency** of an event is simply number of times that the event occurs.
- ❑ For example, if you flip a coin seven times and the coin lands heads up twice, then the absolute frequency of heads is 2.
- ❑ The **relative frequency** of an event is the absolute frequency of the event divided by the total number of trials.
- ❑ Since you tossed the coin seven times in the example above, the total number of trials is 7.
- ❑ Therefore, the relative frequency of heads is  $\frac{2}{7} \approx 0.29$ . Note that the relative frequency is a fraction or a proportion.

## Exercise 1: Recognizing Individuals as Unique

- ❑ To find the relative frequency of students using the different characteristics, you will use the total number of students in the class and compare that total to the numbers you used in your first bar graph for each characteristic.
- ❑ For example, if 28 students participating in the leaf activity, and 11 students out of the group of 28 students used leaf size to find their leaf, you have a ratio of 11:28.
- ❑ That ratio can also be written as a fraction with the numerator 11 and the denominator 28, or  $\frac{11}{28}$ . You then find the decimal equivalent of the fraction. You will want to use a calculator.
- ❑ **Example:**  $\frac{11}{28} = 11 \div 28 = 0.392857\dots$
- ❑ Since the decimal number in this example has many digits, round the decimal number to the thousandths place so that it is easier to work with.  $\rightarrow 0.392857\dots \approx 0.393$  ( $\approx$  means *approximately or nearly equal to*)

## Exercise 1: Recognizing Individuals as Unique

- ❑ Relative frequencies are related to percentages in the following way. If you multiply the decimal number by 100, this would give you the percent equivalent of your decimal number.

**Example:**  $0.393 \times 100 = 39.3\%$

- ❑ Find the relative frequency of each characteristic for the group of students participating in the activity using the procedure described in the above example.
- ❑ Once you find the relative frequencies for each characteristic, find the sum of all your relative frequencies. The sum of all your relative frequencies should be very close to 1, or the sum may be exactly 1. (The sum may not be exactly 1 if you rounded some of the decimals as was done in the above example.)

## Exercise 1: Recognizing Individuals as Unique

- ☐ Why should the sum be 1, or very close to 1?
- ☐ When you are working with relative frequencies, 1 indicates *1 whole*.
- ☐ Another way to think about this is to think about the relationship between relative frequency and percentages.
- ☐ A relative frequency of 1 is equal to 100%.
- ☐ If you eat 100% of a pizza, you eat the whole pizza.
- ☐ If you get a 100% on a math test, all of your answers were correct!
- ☐ Your relative frequencies should have a sum of 1 (or close) to indicate the whole group of students participating in the activity.

## Exercise 1: Recognizing Individuals as Unique

- ❑ The relative frequency is a useful statistic because it can be used to compare the outcomes of experiments with different numbers of trials.
- ❑ For example, suppose Mrs. Brooks' 5<sup>th</sup> grade class has 30 students, and Mrs. Tichnour's class has 20 students.
- ❑ Both classes take the same science exam. Seven students in Mrs. Brook's make an A+, while six students in Mrs. Tichnour's class make an A+.
- ❑ However, since Mrs. Tichnour's class had fewer students than Mrs. Brook's class, this does not necessarily mean that Mrs. Brooks' class did better on the exam than Mrs. Tichnour's class.
- ❑ **Q1.** Calculate the relative frequency of an A+ in each class. Which class did better on the exam? **Click for the answer!**
- ❑ **Mrs. Tichnour's class did better on the exam, (relative frequency of A+'s of 0.3), compared to Mrs. Brooks' class (0.233)**

## Exercise 1: Recognizing Individuals as Unique

- ☐ **Q2.** Which trait(s) yielded the most successes? Are the traits with more successes necessarily the best ones to use when identifying leaves? Why or why not? How could we change the game to make the number of successes that belong to a trait a better measure of how effectively a trait can be used to identify leaves? **Click for the answer!**
- ☐ The traits with the most successes are not necessarily the best ones to use when identifying leaves.
- ☐ For example, these traits may have yielded more successes because they were more often employed, or it could be that some traits work well for certain people but less well for others.
- ☐ There are many ways that we could alter the game to make the number of successes a better measure of how effectively a trait can be used to identify a leaf. If instead we assigned each trait to an equal number of students then the number of successes that each trait yielded would be a better measure of how effective the trait can be used to identify leaves.

## Exercise 1: Recognizing Individuals as Unique

- ❑ Calculate the success rate of each trait to see how the success rate varied with the trait used for identification. Record the trait specific success rates in your table.

$$\text{trait success rate} = \frac{\text{\# of successes that belong to trait}}{\text{absolute frequency of trait}} \times 100$$

- ❑ **Q3.** Which trait(s) yielded the highest success rates? Are the traits with higher success rates necessarily the best ones to use when identifying leaves? Why or why not? How could we change the game to make the trait success rate a better measure of how effectively a trait can be used to identify leaves? **Go to the next slide for the answer!**



## Exercise 1: Recognizing Individuals as Unique

- ❑ **Q3.** Which trait(s) yielded the highest success rates? Are the traits with higher success rates necessarily the best ones to use when identifying leaves? Why or why not? How could we change the game to make the trait success rate a better measure of how effectively a trait can be used to identify leaves?
- ❑ The traits with the highest success rates are not necessarily the best ones to use when identifying leaves. If a trait was employed by a single person, and that person was successful at identifying their leaf then the trait's success rate would be a perfect 100%. However, it could be that the trait is only effective at identifying that one particular leaf, or that the person was just very good at using that trait. There are many ways that we could alter the game to make the success rate a better measure of how effectively a trait can be used to identify a leaf. For example, we could add more leaves and require each student to identify multiple leaves.

## **Exercise 1: Recognizing Individuals as Unique**

- ☐ You are now going to use the data your teacher collected to make a bar graph indicating the leaf characteristics students used to remember their leaves.
- ☐ Your bar graph will display a visual comparison of the data which should be understood by anyone who might look at the graph. For example, someone should be able to look at the graph and be able to answer the following questions:
  - ☐ Which characteristics were used by more students to find their leaves?
  - ☐ Which characteristics were not used by many students?

## Exercise 1: Recognizing Individuals as Unique

- ☐ Now, **you** should answer the following questions, based on your class data:
  - ☐ Which characteristic was used by the *most* students?
  - ☐ How many students used that characteristic to find their leaves?
- ☐ You will use this number to determine the range of your vertical scale for your graph.
- ☐ Your vertical scale will begin at 0 and increase at equal intervals as you go up the vertical axis. Your largest number will be greater than or equal to the number of students in the group of the 'most-used' characteristic.

## Exercise 1: Recognizing Individuals as Unique

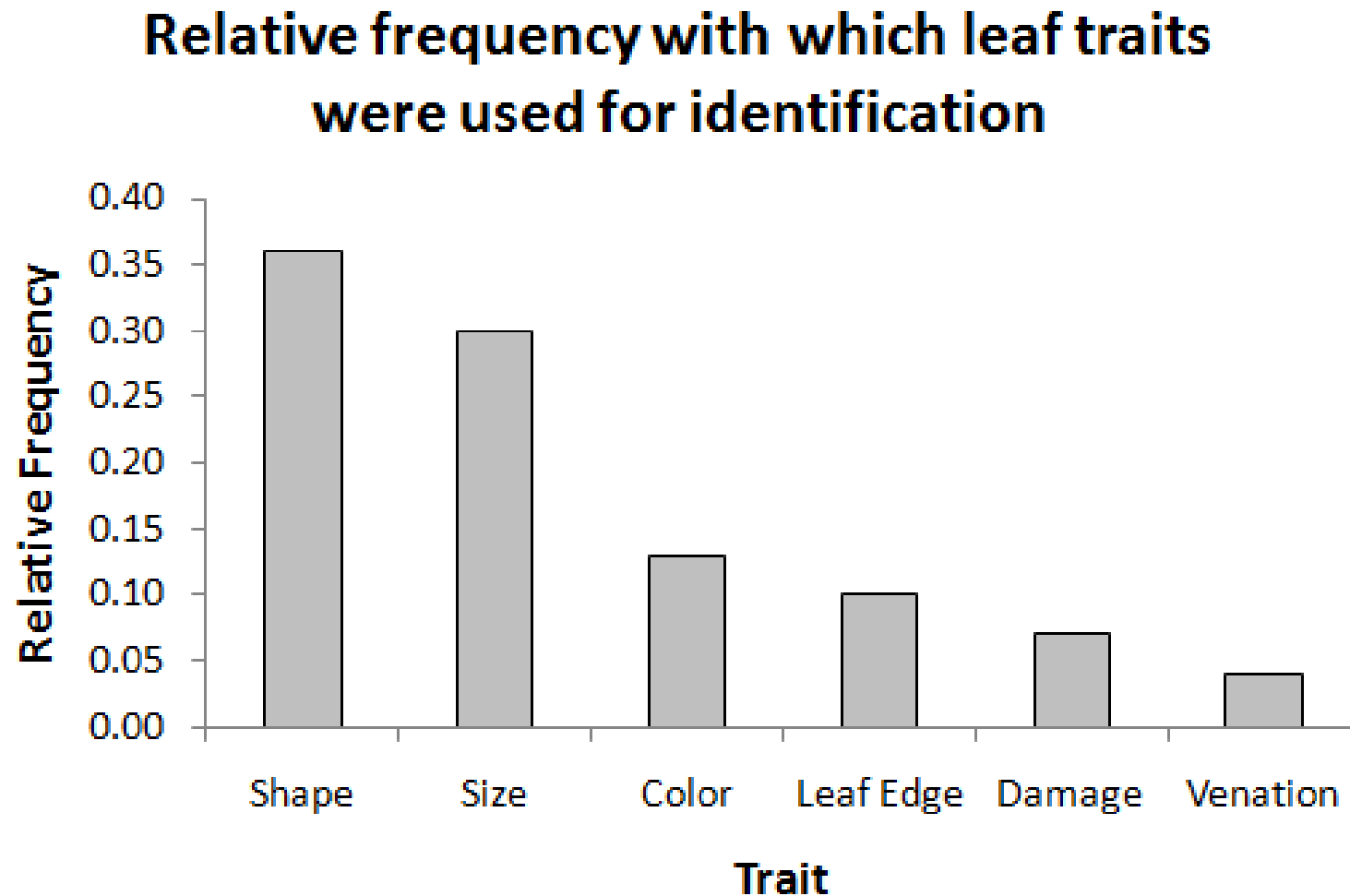
- ❑ Determine your interval size so that your graph clearly displays the data and the related labeling.
- ❑ For example, suppose 17 students used leaf *shape* as the primary characteristic to find their leaves.
- ❑ You might decide to count by 2's on your vertical scale, and since the largest number you need to show is 17, your last number on the vertical scale might be 18.
- ❑ There is really no need to go much beyond 18 on the graph since your largest number is 17.
- ❑ If the largest number you need to show is 18 and you are using an interval of 2, you can stop at 18 or you might go one interval beyond 18 and stop at 20.
- ❑ Whatever interval you choose, be sure your graph is large enough to clearly indicate comparisons of your data, but also fit on your paper.

## **Exercise 1: Recognizing Individuals as Unique**

- ☐ You will also make a second graph using the same data set, but this time comparing relative frequencies of students using certain characteristics rather than the numbers of students.
- ☐ Using the relative frequency data you have just found, construct a bar graph. The primary difference from your first graph will be your vertical scale, which will indicate relative frequencies rather than numbers of students as in your first graph.
- ☐ What was the largest relative frequency of any one characteristic? That largest relative frequency tells you how far up your vertical scale should go. For example, if your largest percentage is 0.393, you will not need to go any higher (or much higher) than that number on your vertical scale (Example: if your interval is 0.10, then you might stop at 0.40 if the largest relative frequency is 0.393).
- ☐ Determine your intervals for your vertical scale so that your graph is large enough to clearly indicate comparisons of your data, but also fit on your paper.

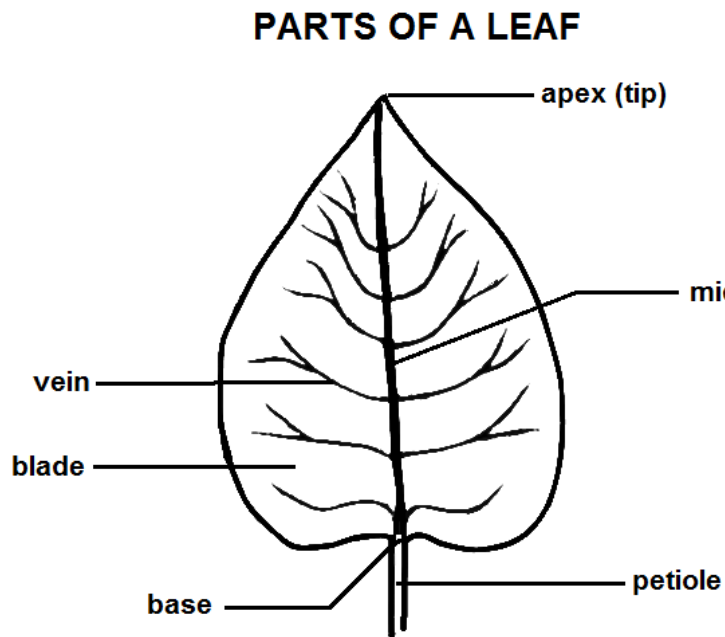
## Exercise 1: Recognizing Individuals as Unique

- Below is an example of what a graph of relative frequencies of correct identification of leaves using particular traits might look like:

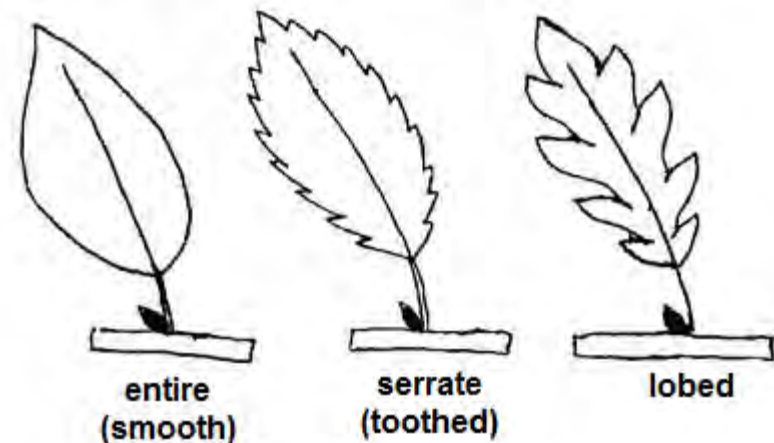


# Exercise 1: Recognizing Individuals as Unique

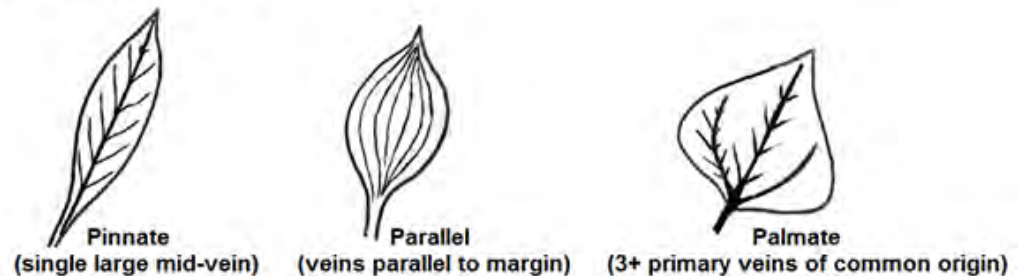
- ❑ Look at the images below to identify other leaf traits that might vary among species and individuals.
- ❑ Have each student pick a new leaf and play the game again.
- ❑ Calculate the new class success rate to see if it increased.



**MAJOR LEAF MARGIN TYPES**



**LEAF VENATION**



## Exercise 2: Leaf Match

- ☐ In this exercise, you will use all of the leaves in Container A, and try to identify them by trying to match them with pictures of leaves.
- ☐ Below each picture you will find the common name and the scientific name of the tree species from which the leaf came.
- ☐ The scientific name consists of two parts: the genus (close relatives will all have this name) and the species (only individual trees that might possibly interbreed share this name).
- ☐ On a separate sheet of paper, write the numbers 1-35. When you examine a particular leaf, note its number, and write the name of the tree species to which you think that leaf belongs beside that number on your answer sheet. See if you can identify the species of tree from which each leaf came.
- ☐ Your teacher may wish to take a tally of student answers to see if there is a consensus, or if there is disagreement about the identification of particular leaves. If there is any disagreement on a particular leaf, you may wish to use a field guide/the internet to see if a consensus can be reached.





# Guide to Leaves in Unit 8

## MAPLE FAMILY (ACERACEAE)



Japanese Maple  
*Acer palmatum*



Red Maple  
*Acer rubrum*



Silver Maple  
*Acer saccharinum*



Sugar Maple  
*Acer saccharum*

## SWEET GUM FAMILY (ALTINGIACEAE)



Sweet Gum  
*Liquidambar styraciflua*

## HOLLY FAMILY (AQUIFOLEACEAE)



American Holly  
*Ilex opaca*

## DOGWOOD FAMILY (CORNACEAE)



Flowering Dogwood  
*Cornus florida*

## BEAN & PEA FAMILY (FABACEAE)



Eastern Redbud  
*Cercis canadensis*



# Guide to Leaves in Unit 8

## BEECH & OAK FAMILY (FAGACEAE)



Chinese Chestnut  
*Castanea mollissima*



American Beech  
*Fagus grandifolia*



White Oak  
*Quercus alba*



Southern Red Oak  
*Quercus falcata*



Blackjack Oak  
*Quercus marilandica*



Chestnut Oak  
*Quercus prinus*



Northern Red Oak  
*Quercus rubra*

## GINGKO FAMILY (GINGKOACEAE)



Ginkgo  
*Ginkgo biloba*

## LAUREL FAMILY (LAURACEAE)



Sassafras  
*Sassafras albidum*





# Guide to Leaves in Unit 8

## MAGNOLIA FAMILY (MAGNOLIACEAE)



Tulip Poplar  
*Liriodendron tulipifera*

## MALLOW FAMILY (MALVACEAE)

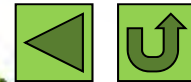


American Basswood  
*Tilia americana*

## MULBERRY FAMILY (MORACEAE)



Paper Mulberry  
*Broussonetia papyrifera*



## MULBERRY FAMILY (MORACEAE)



Red Mulberry  
*Morus rubra*

## PLANE-TREE FAMILY (PLATANACEAE)



Eastern Sycamore  
*Platanus occidentalis*

## ROSE FAMILY (ROSACEAE)



Black Cherry  
*Prunus serotina*

## ELM FAMILY (ULMACEAE)



American Elm  
*Ulmus americana*



## Exercise 3: Using Mathematics to Describe a Population

- ☐ When scientists study populations, they are typically interested in knowing several **parameters**, or characteristics of those populations, such as the “most typical” value of a trait, or the amount of variation present in the populations.
- ☐ One way to examine these parameters would be to measure or categorize every individual in the populations.
- ☐ Unfortunately many populations are so large, or difficult to access, that it would be impossible to examine and describe each individual in the population.
- ☐ For example, imagine trying to measure the length of every ant in an ant hill, or the weight of every cardinal that passes through your yard.

## Exercise 3: Using Mathematics to Describe a Population

- ❑ Since scientists often can't examine every individual in a population, they often must settle for examining a **sample**, or subset of the population.
- ❑ Then, the traits of individuals in the sample can be described by numbers or categories, and this information used to calculate **statistics** that summarize the data.
- ❑ These sample statistics serve as estimates of population parameters.
- ❑ When using sample statistics to make inferences about a population, they make a very important assumption.
- ❑ They assume that the sample is representative of the population as a whole.
- ❑ In order for this assumption to be valid, scientists must be very careful when they select the sample individuals.

## Exercise 3: Using Mathematics to Describe a Population

❑ See if you can answer the following questions:

**Q1.** Suppose that you wanted to find out what brand of pants are most often worn by fifth grade boys in a small town. Which of the following samples do you think would best answer this question? Why? What is wrong with the other samples?

- a) The boys in Mrs. Brooke's fifth grade class
- b) The boys whose last names begin with the letters A-D or M-P.
- c) The boys that ride bus 23
- d) The boys that sit together in the far right corner of the cafeteria

**CLICK TO GO TO THE NEXT SLIDE FOR THE ANSWER!**

### Exercise 3: Using Mathematics to Describe a Population

- ☐ Sample b is probably the best sample to use when answering this question, because the boys in sample b are not likely to be linked in ways that affect the brand of pants that they wear.
- ☐ The boys in sample a, c, and d, see each other every day and so they might influence each other.
- ☐ The boys in sample c live in the same neighborhood and so they probably belong to the same socio-economic class, thus their parents may shop for the same brand of pants.
- ☐ The boys in sample d are likely friends and so they may be similar in many additional ways that might cause them to prefer the same brand of pants.

## Exercise 3: Using Mathematics to Describe a Population

**Q2. What if instead you wanted to know the average height of a fifth grade boy? Could any of the samples that you rejected before be used to answer this new question?**

- a) The boys in Mrs. Brooke's fifth grade class
- b) The boys whose last names begin with the letters A-D or M-P.
- c) The boys that ride bus 23
- d) The boys that sit together in the far right corner of the cafeteria

**CLICK FOR THE ANSWER!**

☐ Sample a or b could be used to answer this question. We probably shouldn't use sample c or d because these boys likely belong to the same socio-economic class, and so they may have similar diets, which in turn affects their growth.



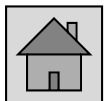
## Exercise 3: Using Mathematics to Describe a Population

- ❑ In the following exercises, you will examine leaves, and use these leaves to help you understand how sample statistics are calculated, and how these statistics are used to describe populations.
- ❑ Decide, as a class, a particular trait to measure on your leaves, for example, leaf blade length, greatest blade width, leaf area (estimated as the product of blade length and greatest blade width), etc.
- ❑ Each student should select a leaf from Container A, and take the measurement chosen above, rounding their measurement to the nearest centimeter (or  $\text{cm}^2$  in the case of area), and record their measurement on the board.
- ❑ After all students have measured their leaves, you should record all of these values in an ordered list, from smallest to largest, like the example to the right.

[illegible]

## Exercise 3: Using Mathematics to Describe a Population

- ❑ Click [HERE](#) to go to Exercise 3a, where students in grades 4-12 can learn how to calculate measures of central tendency.
- ❑ Click [HERE](#) to go to Exercise 3a.2, where students in grades 9-12 will learn about sigma notation.
- ❑ Click [HERE](#) to go to Exercise 3b, where students in grades 5-12 will learn how to calculate measures of spread.
- ❑ Click [HERE](#) for a mini-challenge on estimating square roots.
- ❑ Click [HERE](#) to go to Exercise 3b.2, where students in grades 9-12 will conduct a simulation that illustrates why the formula for sample variance is different than that for population variance.
- ❑ Click [HERE](#) to go to Exercise 3c, where students in grades 5-12 will learn about graphically visualizing measures of central tendency & spread.
- ❑ Click [HERE](#) to go to Exercise 3d, where students in grades 9-12 will learn about how statistical tests can be used to compare populations.



## Exercise 3a: Measures of Central Tendency

- ❑ Trait values vary between individuals, but in a sample of individuals, some values are more typical than others.
- ❑ For instance, in the fall when leaves are changing colors, some trees, such as willows, have leaves that are primarily yellow in color, while other trees, such as oaks, have leaves that are primarily brown in color.
- ❑ According to our visual observations, these are the most common leaf colors for willows and oaks in the fall. However, someone else might disagree and say that oak leaves are primarily red in the fall.
- ❑ Based on observation alone, there's no way to know for certain who is correct.
- ❑ If, however, we can measure the value of a trait, then we can assign a numerical value to each individual in our sample and use mathematical statistics called **measures of central tendency**, to decide which value is the most typical.



## Exercise 3a: Measures of Central Tendency

- ❑ After you have found the median of your sample data, now draw a table with two columns. Label the first column 'Values Observed' and the second column 'Number of Observations'.
- ❑ In the first column list the values that appear in your ordered list from least to greatest, eliminating any repeat values. In the second column list the number of times that each value from the first column appears in your ordered list. Title your table appropriately. See the example at right.
- ❑ Now you are ready to find the **mode** of your data set. The **mode** is another measure of central tendency, and is the value that appears the most often. There are two modes for the example leaf width data set, because 5 cm and 9 cm both appear 10 times, more times than any other values.

**Observed leaf widths**

| <b>Value</b> | <b>Absolute Frequency</b> |
|--------------|---------------------------|
| 3            | 3                         |
| 5            | 10                        |
| 6            | 4                         |
| 8            | 2                         |
| 9            | 10                        |
| 19           | 1                         |

## Exercise 3a: Measures of Central Tendency

- ❑ You can also find the mean of your data set.
- ❑ The **mean** of a data set is the average of the data entries. To find the mean of your data set, add all of your data entries together and then divide by the total number of data entries.
- ❑ You can save time by using your table to help compute the mean. Instead of adding all of the numbers individually like this:  $3 + 3 + 3 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + \dots$

- ❑ You can add them up in groups, like this:

$$\begin{aligned} &3(3) + 10(5) + 4(6) + 2(8) + 10(9) + 1(19) \\ &= 9 + 50 + 24 + 16 + 90 + 19 = 208 \end{aligned}$$

- ❑ In the expression above, the numbers in parentheses are observed values from the sample, and the numbers before the parentheses are the number of times those values appear in the sample. Since there are 30 data entries, the mean of this data set (rounded to the nearest cm) is  $\frac{208}{30} = 6.93 \text{ cm} \approx 7 \text{ cm}$ .

## Exercise 3a: Measures of Central Tendency

- ☐ The mean, like the mode and the median, is also a measure of central tendency.
- ☐ Since there are multiple measures of central tendency, it is up to you to decide which measure (the median, the mode, or the mean) best represents the most typical trait value.
- ☐ In the example leaf width data set, the modes are probably the best measure of central tendency because over half of the leaves in this sample have leaf widths that are equal to one of the two modes.
- ☐ On the next slide are two other example data sets.
- ☐ Compute the mean, median, and mode for each set. Then try to answer the following question:
- ☐ **Which measure of central tendency best describes each data set, and why?**

## Exercise 3a: Measures of Central Tendency

### Data Set A

| Value | Absolute Frequency |
|-------|--------------------|
| 3     | 2                  |
| 5     | 2                  |
| 6     | 5                  |
| 8     | 2                  |
| 9     | 1                  |

### Data Set B

| Value | Absolute Frequency |
|-------|--------------------|
| 5     | 3                  |
| 6     | 4                  |
| 8     | 2                  |
| 25    | 1                  |

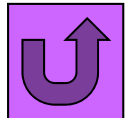
### CLICK FOR THE ANSWERS!

**mean** (to nearest cm) = 6

**median** = 6

**mode** = 6

In Data Set A, all of the measures of central tendency are good descriptors of the typical value, since they are all the same.



**mean** (to nearest cm) = 8

**median** = 6

**mode** = 6

In Data Set B, the median and the mode are both good measures of central tendency.

The mean is too large, because it is heavily influenced by the outlier value of 25.



## Exercise 3a.2: Sigma Notation

- ❑ At some point, you are likely to run across an expression for calculating the mean of a set of data (as well as other sample statistics or other quantities) which uses the symbol  $\Sigma$ , which is the upper-case Greek letter **sigma**.
- ❑ Don't be intimidated by this perhaps unfamiliar symbol, however, as its meaning in mathematical expressions is actually quite simple.
- ❑ In mathematical expressions, the upper-case Greek sigma ( $\Sigma$ ) simply means to "sum up" some quantity. For this reason, **sigma notation** is also sometimes known as **summation notation**. To get you a little more comfortable with sigma notation, let's first look at a few examples.

$$\sum_{i=1}^5 i$$

## Exercise 3a.2: Sigma Notation

$$\sum_{i=1}^5 i$$

- ❑ Look at the example above. We already know, since we see a  $\Sigma$ , that we will be summing up some values. But what values are we summing up? To know the answer to this, we have to look at the other parts of the notation.
- ❑ The " $i$ " to the right of the  $\Sigma$  tells us that we will be adding together values of  $i$ , but we need additional information.
- ❑ The " $i=1$ " below the  $\Sigma$  tells us that "1" is the value of  $i$  with which we should start.
- ❑ The "5" on top of the  $\Sigma$  tells us the upper bound of the summation, or with which value we should stop.
- ❑ In other words, the sigma notation above tells us to add up the integer values of  $i$  from 1 to 5:

$$\sum_{i=1}^5 i = 1 + 2 + 3 + 4 + 5 = 15$$

## Exercise 3a.2: Sigma Notation

□ Now let's try another example:

$$\sum_{i=3}^7 (i^2 - 1)$$

□ In the above example, the sigma notation is telling us to sum the quantity  $(i^2 - 1)$  for all integer values of  $i$  between 3 and 7:

$$\sum_{i=3}^7 (i^2 - 1) = (3^2 - 1) + (4^2 - 1) + (5^2 - 1) + (6^2 - 1) + (7^2 - 1)$$

$$\sum_{i=3}^7 (i^2 - 1) = (9 - 1) + (16 - 1) + (25 - 1) + (36 - 1) + (49 - 1)$$

$$\sum_{i=3}^7 (i^2 - 1) = 8 + 15 + 24 + 35 + 47 = 129$$

## Exercise 3a.2: Sigma Notation

❑ Now see if you can answer the following questions:

**Q4:** Evaluate the following expression:

$$\sum_{i=6}^9 (17 - 2i)$$

**Q5:** Evaluate the following expression:

$$\sum_{i=0}^4 2^i$$

**Q6:** Evaluate the following expression:

$$\sum_{i=3}^6 (-1)^{i+1} (3i + 1)$$

**Q7 (Super Solver Problem):** How could you write "the sum of all multiples of 3 from 6 to 27" in sigma notation?

**CLICK TO GO TO THE NEXT SLIDE FOR THE ANSWERS!**

## Exercise 3a.2: Sigma Notation

**Q4:** Evaluate the following expression:

$$\sum_{i=6}^9 (17 - 2i) = 8$$

**Q5:** Evaluate the following expression:

$$\sum_{i=0}^4 2^i = 31$$

**Q6:**

$$\sum_{i=3}^6 (-1)^{i+1} (3i + 1) = -6$$

**Q7 (Super Solver Problem):** How could you write "the sum of all multiples of 3 from 6 to 27" in sigma notation?

**There are actually multiple possible answers, but three examples are below. Did you find other answers that work?**

$$\sum_{i=2}^9 3i = \sum_{i=0}^7 (3i + 6) = \sum_{i=1}^8 (3i + 3)$$



## Exercise 3b: Measures of Spread

- ❑ Now that you have examined several measures of central tendency, you will examine some measures of spread.
- ❑ First, you will learn about the range.
- ❑ The **range** is the *largest data entry minus the smallest data entry*. For example, the range of the data set on leaf widths to the right is  $19 - 3 = 16\text{cm}$ .
- ❑ The range is a measure of spread, indicating the difference in size between the largest and smallest individuals in a sample.
- ❑ Larger values of the range indicate more spread in the data.

[illegible]

## Exercise 3b: Measures of Spread

- ❑ Another measure of spread is the **variance**.
- ❑ It is important to note that there are two ways of calculating the variance of a population or sample. They are very similar, with one small exception.
- ❑ First, let's learn how you would calculate the variance of a population, if the population were sufficiently small enough to gather data on every individual within it. For simplicity, first assume that the "sample" of leaves in Container A actually represents a sample of every individual in the simulated "population".
- ❑ You are now going to calculate the **population variance** (usually represented as  $\sigma^2$ , read as "sigma squared", since the expression uses lower case Greek letter "sigma" squared) for your leaf widths using these leaves. Follow the steps on the next slide to see how the population variance is calculated.

## Exercise 3b: Measures of Spread

- ❑ To calculate the **population variance ( $\sigma^2$ )**, when you have measured every individual in the population:
- ❑ First subtract each value from the mean value. If you have 30 data points, you will subtract each of the 30 data points from the mean.
- ❑ Find the square of each subtraction. For example, if one of your data points was 4 and the mean was 8, you subtract 4 from 8:

$$8 - 4 = 4$$

- ❑ Now square this value (multiply it by itself). For example:

$$4^2 = 4 \times 4 = 16$$

- ❑ Do this same procedure for each of your measurements.
- ❑ When you have found all your these values, add them all together.
- ❑ When you have your sum of subtraction values, divide that sum by the total number of measurements (also referred to as ***N***, or the population size).
- ❑ The result of this division is equal to the **population variance**.



## Exercise 3b: Measures of Spread

- ❑ On the previous slide, you calculated the population variance for the trait that your class chose to measure.
- ❑ The larger the value for variance as it compares to the mean of your data, the greater variability in leaf size among the leaves in the sample. Below is an example of calculating the variance of leaf widths in the example data set to the right.

$$\begin{aligned} & \frac{3(3-7)^2+10(5-7)^2+4(6-7)^2+2(8-7)^2+10(9-7)^2+1(19-7)^2}{30} \\ &= \frac{3(-4)^2+10(-2)^2+4(-1)^2+2(1)^2+10(2)^2+1(12)^2}{30} \\ &= \frac{3(16)+10(4)+4(1)+2(1)+10(4)+1(144)}{30} \\ &= \frac{48+40+4+2+40+144}{30} = \frac{278}{30} \approx 9.27 \approx 9 \end{aligned}$$

[illegible]

## Exercise 3b: Measures of Spread

- ❑ In the previous steps, we computed the **population variance**, which is used when one can measure every individual within a population.
- ❑ However, it is almost always impossible for scientists to collect data on every individual within a population, so they usually must settle for collecting data on a sample from that population in order to estimate the typical values and variability within the entire population.
- ❑ As it turns out, the method of calculating variance as presented earlier is not always a very good estimate of the *true population variance* if one is using a sample that does not consist of the entire population.
- ❑ For this reason, calculating the **variance of a sample** (which is used to estimate the true population variance, which cannot typically be known) is done in a slightly different way.

## Exercise 3b: Measures of Spread

- ❑ To estimate the population variance from the sample data, the **sample variance** (usually represented as  $\sigma$ , the lower case Greek letter sigma) is used.
- ❑ To calculate the sample variance, proceed as if you were calculating the population variance, but in the final step divide by the **sample size minus 1 ( $n-1$ )**.
- ❑ **NOTE:**  **$N$**  (upper case) is usually used to represent a population size, while  **$n$**  (lower case) is usually used to represent a sample size.
- ❑ For example, the sample variance of the leaf width data (which we would use to estimate the variance of the population from which the leaf width data was drawn) would be

$$\frac{278}{29} \approx 10$$

## Exercise 3b: Measures of Spread

- ❑ The **standard deviation** is another measure of spread.
- ❑ The standard deviation is simply the square root of the variance.
- ❑ For example, the **population standard deviation** (represented by  $\sigma$ , the lower case Greek letter "sigma") is the square root of the population variance  $\sigma^2$ , and the **sample standard deviation** (usually represented by  $s$ ) is the square root of the sample variance  $s^2$ .
- ❑ For example, both the "population" standard deviation and "sample" standard deviation of the leaf width data from the previous slides are approximately 3 (if rounding to the nearest cm, though the sample variance is actually larger, and likely a better estimate of the *true* population variance).
- ❑ **Like the range, the variance and the standard deviation are also measures of spread. In particular, they measure how your data is spread about the mean. Larger values of the sample variance and standard deviation indicate more spread in the data.**

## Exercise 3b: Measures of Spread

**Q8 (Super Solver Problem):** If you completed Exercise 3a.2, how would you write the formulas for population variance and sample variance using sigma (summation) notation?

**CLICK FOR THE ANSWER!**

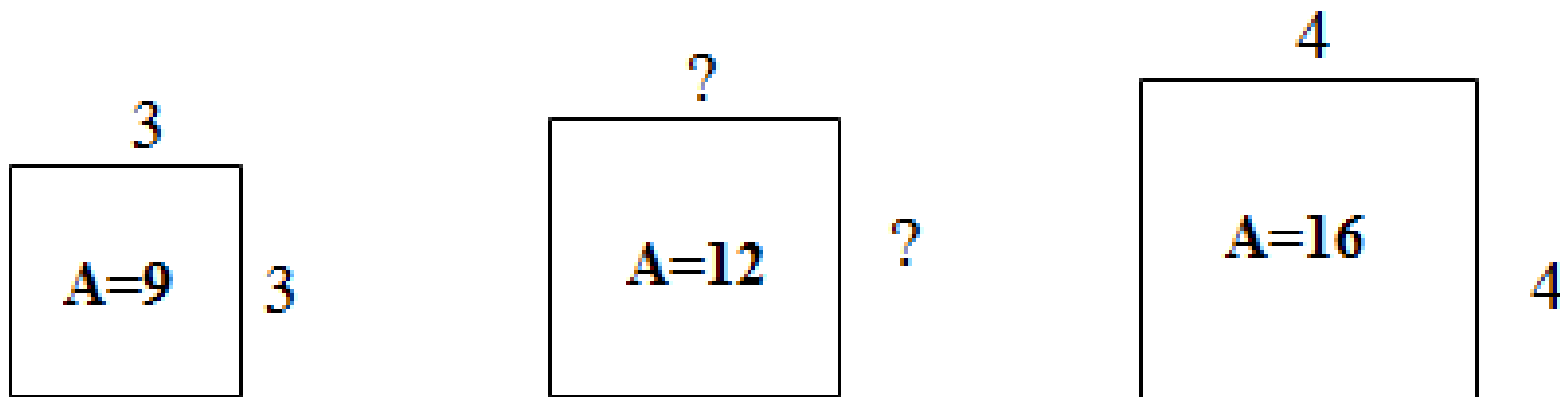
$$\textit{Population variance } (\sigma^2) = \frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2$$

$$\textit{Sample variance } (s^2) = \frac{1}{(n-1)} \sum_{i=1}^n (x_i - \bar{x})^2$$



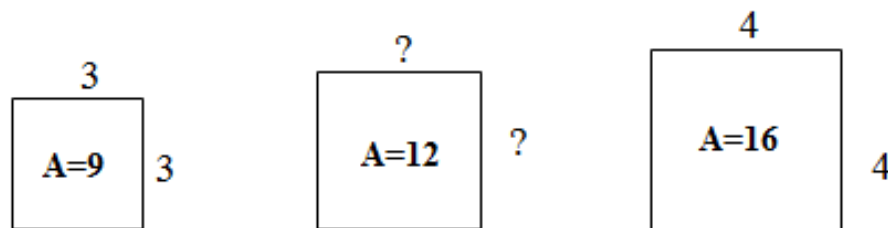
## Mini-Challenge: Estimating Square Roots

- Look at the three squares below and notice the side lengths that are labeled on the first and last squares.



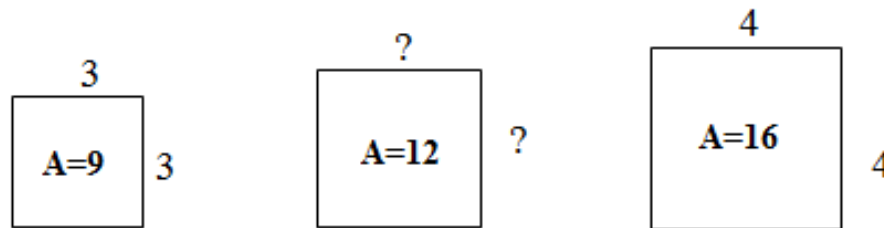
- The first square has a side length of 3, and the last square has a side length of 4.
- The areas of all three squares are also labeled. The first square has an area of 9 because  $3 \times 3 = 9$ , and the last square has an area of 16 because  $4 \times 4 = 16$ .
- What will the side lengths be for the middle square if the area of the square is 12?
- Remember that the definition of a square tells us all sides must have equal length.

## Mini-Challenge: Estimating Square Roots

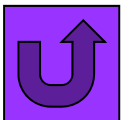


- ☐ The square in the middle does not have its side length labeled so you are going to determine what the side length must be to have an area of 12.
- ☐ If you know the smallest square has a side length of 3 and the largest square has a side length of 4, what can you say about the length of the middle square?
- ☐ How does the size of the middle square relate to the other two squares? Both 3 and 4 are whole numbers, but will the missing number be a whole number? Why, or why not?

## Mini-Challenge: Estimating Square Roots



- ☐ How do you think you might find the side length of that middle square?
- ☐ Use your calculator to help you find the missing side length, but do not use the square root key (*that would be cheating!*).
- ☐ Use your estimation skills to help you begin choosing side lengths to test to find the actual side length.
- ☐ When you believe you have the side length, test your answer by multiplying the number by itself (squaring the number). How close is the square of your number to 12?
- ☐ Continue testing numbers until you have a number to the hundredths place that gets as close as possible to 12 when squared.





### Exercise 3b.2: Sample variance vs population variance

- ❑ In the previous exercise, you learned that there is a slight difference in calculating the variance of a sample versus the variance of a population (which can only be calculated if every individual within the population has been measured).
- ❑ Remember, the denominator in the equation for sample variance is equal to  **$(n-1)$** , where  **$n$**  is the number of individuals in the sample.
- ❑ The denominator in the equation for the population variance is equal to  **$N$**  (the total number of individuals in the population).
- ❑ This exercise will illustrate **WHY** these formulas are different.

## Exercise 3b.2: Sample variance vs population variance

- ☐ Your teacher should locate the container marked "Exercise 3b.2," which contains a bag of beads of the same size and shape, but of two different colors.
- ☐ All of the beads in this bag represent a population, with each bead representing an individual within the population.
- ☐ Your teacher knows the total number of beads, as well as the number of beads of each color in the bag, but will not reveal this information to the class until you have all conducted the rest of the exercise.
- ☐ Each color of beads will be assigned a particular value, and your teacher will inform you which color takes which value:
  - ☐ One color of beads will be given a value of 1.
  - ☐ One color of beads will be given a value of 5.
- ☐ Your teacher should now shake the bag of beads to mix them, and approach one student in the class.

## Exercise 3b.2: Sample variance vs population variance

- ❑ That student should reach into the bag, and withdraw a sample of 3 beads ( $n=3$ ), recording on a piece of paper the color of each, and the value assigned to each of the two colors.
- ❑ Those beads should be placed back into the bag, and the bag shaken again.
- ❑ This procedure should be repeated until every student has taken a sample of 3 individuals from the "population".
- ❑ Each student should now make a table like the one below, and calculate the appropriate values for their sample, rounding their calculated values to the nearest hundredth.

| Sample Values |  |  | Sample Mean | Sample Variance ( $s^2$ )<br>Using $n$ as<br>the denominator | Sample Variance ( $s^2$ )<br>Using $(n-1)$ as<br>the denominator |
|---------------|--|--|-------------|--|--|
|               |  |  |             |  |  |

### Exercise 3b.2: Sample variance vs population variance

- ❑ After all students have calculated their values for the means and variances (using both methods) for their samples, your teacher should make a table with three columns ("Mean", "Variance Using  $n$ ", and "Variance Using  $(n-1)$ ") on the board, and compile students' results.
- ❑ After all students' results are compiled on the board, you should calculate the average variance for all samples when using both methods ( $n$  versus  $n-1$  in the denominator).
- ❑ Your teacher will now reveal the true population variance ( $\sigma^2$ ) to the class.
- ❑ Compare this value to the average sample variances obtained when using both  $n$  and  $(n-1)$  in the denominator.

## Exercise 3b.2: Sample variance vs population variance

❑ Now answer the following question:

**Q9:** What do you notice about the average values of sample variance ( $s^2$ ) using  $n$  versus  $(n-1)$  in the denominator of the equation when compared to the true population variance ( $\sigma^2$ )?

**CLICK FOR THE ANSWER!**

You should notice that the average sample variance using  $n$  in the denominator is smaller than the true population variance. In other words, the use of  $n$  in the denominator tends to underestimate the true amount of variance in the whole population. The average sample variance when using  $(n-1)$  in the denominator is a much better estimate of the true population variance. This is why the formula for finding sample variance uses  $(n-1)$  in the denominator instead of  $n$ !

## Exercise 3b.2: Sample variance vs population variance

- ☐ Now, look at the values under the "Mean" column on the board.
- ☐ Using the tally marks representing the number of samples in which each mean was calculated for the samples, and calculate the mean of **all of the sample means**.
- ☐ Your teacher will now let you know the true population mean.
- ☐ Compare the value you calculated as the mean of the class's sample means to the true population mean ( $\mu$ ), and answer the following questions:

**Q10:** In effect, what are you doing when you are calculating the mean of all students' sample means?

**Q11:** Compare your calculated value of the mean of all students' sample means, as well as each of the individual sample means obtained, to the true population mean. Which value is closest to the true population mean? Considering your answer to **Q10**, what does this tell you?

- ☐ **Go to the next slide for the answers!**

## Exercise 3b.2: Sample variance vs population variance

**Q10:** In effect, what are you doing when you are calculating the mean of all students' sample means?

**CLICK FOR THE ANSWER!**

When calculating the mean of all sample means, you are essentially pooling the data from each sample, and calculating the sample mean of a much larger sample size.

## Exercise 3b.2: Sample variance vs population variance

**Q11:** Compare your calculated value of the mean of all students' sample means, as well as each of the individual sample means obtained, to the true population mean. Which value is closest to the true population mean? Considering your answer to **Q10**, what does this tell you? **CLICK FOR THE ANSWER!**

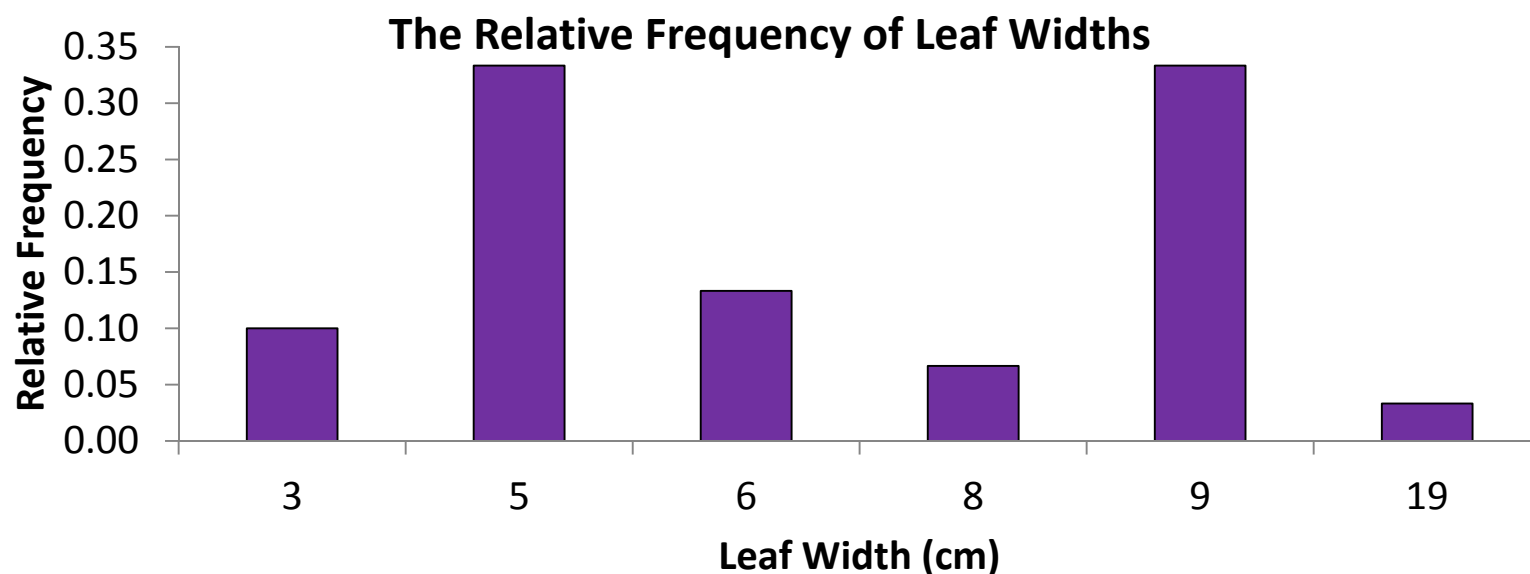
You should notice that some sample means (of size  $n=3$ ) are lower, and some are higher, than the true population mean. However, when all of these samples are pooled to make a much larger sample size, the resulting sample mean is much closer to the true population mean. This illustrates the fact that the larger the sample size, the better the sample mean is as an estimate of the true population mean. This also holds true for sample statistics that estimate variation in a population (variance and standard deviation). This is why scientists typically use the largest sample sizes that time & funding allow, as larger sample sizes give them greater confidence that their estimates of characteristics of entire populations are close to their actual values.



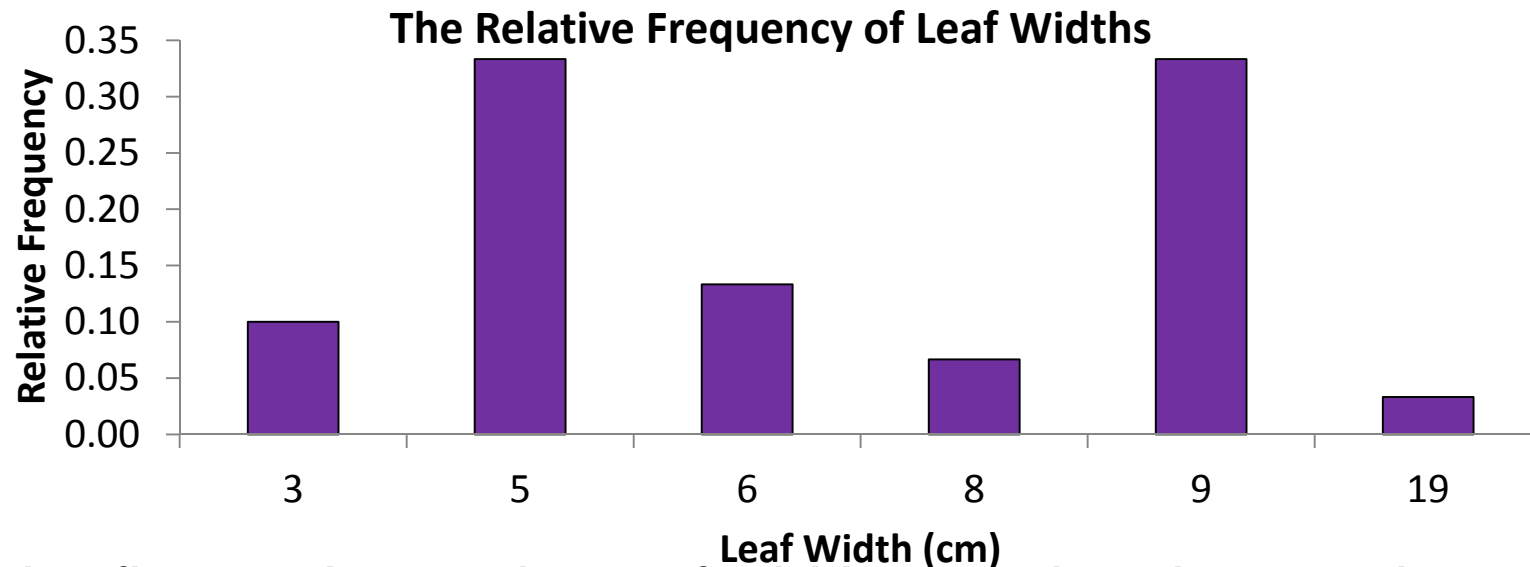


## Exercise 3c: Visualizing measures of central tendency & spread

- ❑ A **relative frequency bar graph** can help you to visualize how your data is distributed.
- ❑ For example, by looking at a bar graph, you can see how spread out the data is, and estimate the central tendency of the data.
- ❑ You can also use a relative frequency bar graph to find the probability that a data entry belongs to a particular category.
- ❑ The figure below is a relative frequency bar graph of the sample leaf width data presented earlier in Exercise 3a.



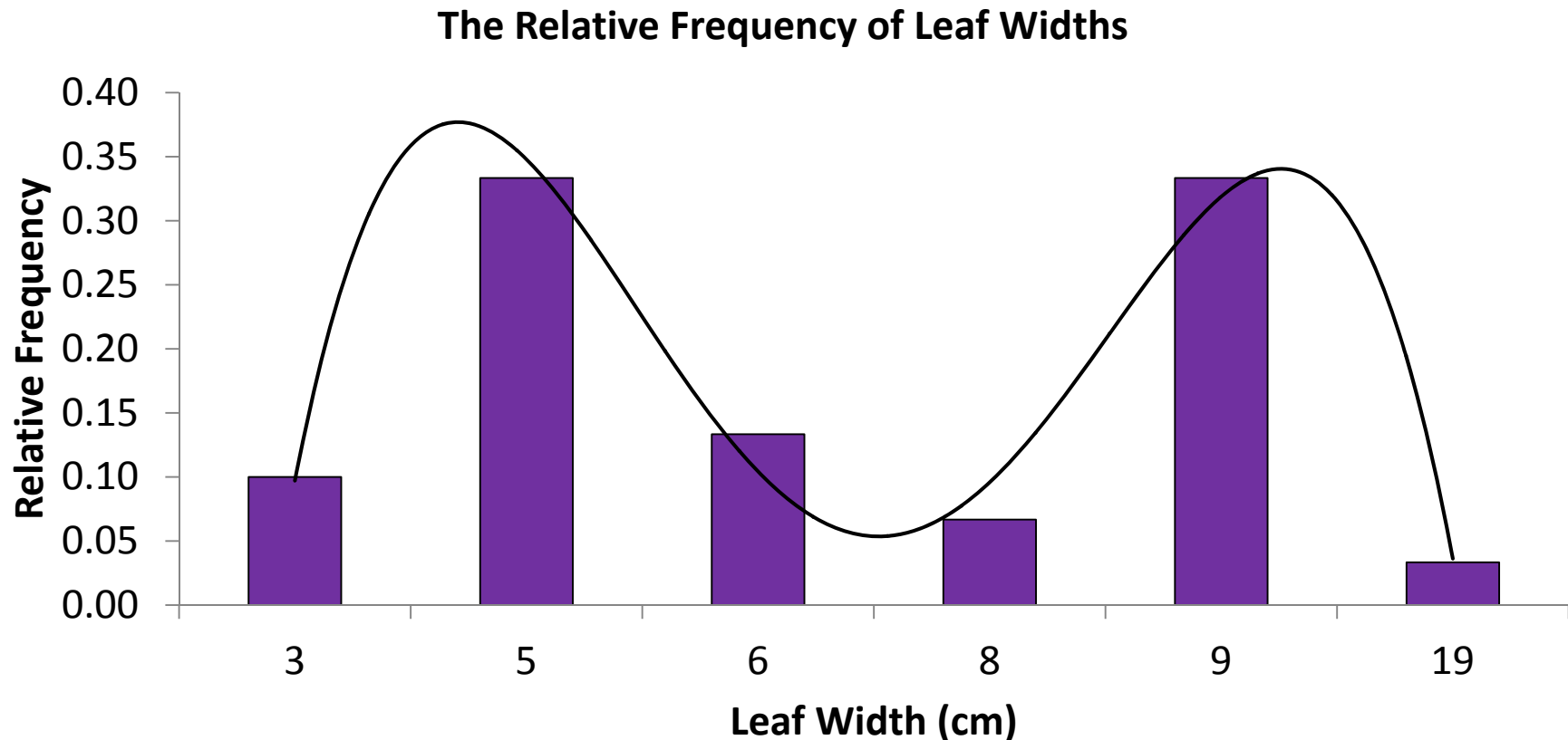
## Exercise 3c: Visualizing measures of central tendency & spread



- ☐ In the figure above, the leaf widths are listed along the horizontal or x-axis of the graph.
- ☐ The relative frequency of each leaf width is plotted along the y-axis.
- ☐ This data set is **bimodal** (has two modes) about which the data values are clustered.
- ☐ We can also see that the relative frequency of 3 cm is 0.1. This means that if we select a leaf at random from our sample, then probability that the leaf's width is 3 cm is 0.1.

## Exercise 3c: Visualizing measures of central tendency & spread

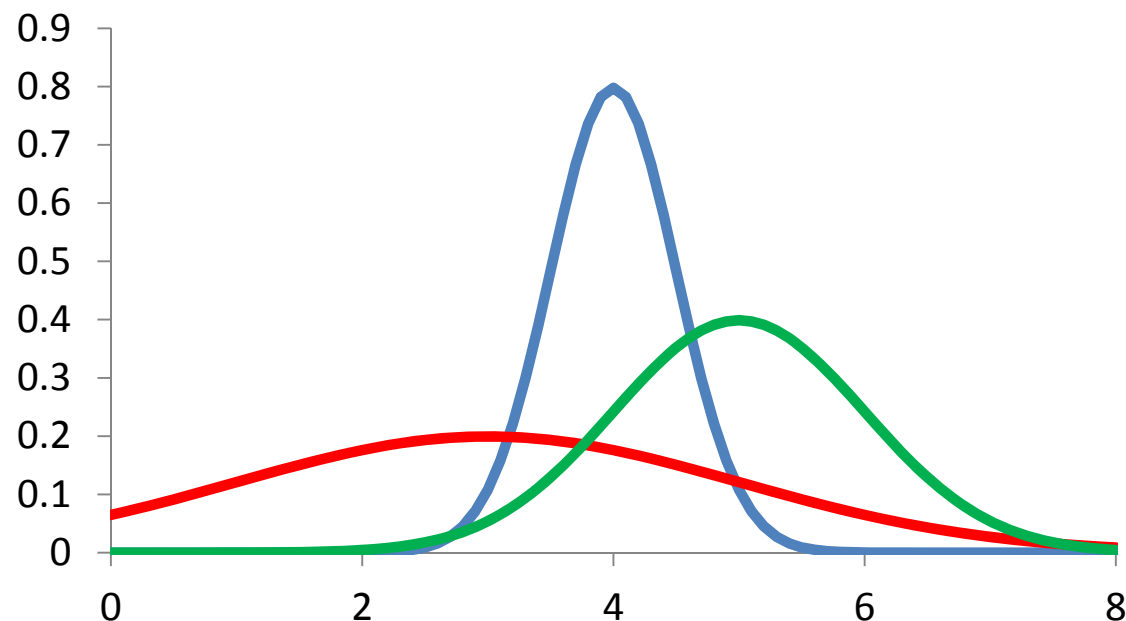
- Now imagine that we wanted to draw a smooth curve to describe the shape of our data. In the case of the leaf width bar graph the curve might look like the one pictured below.



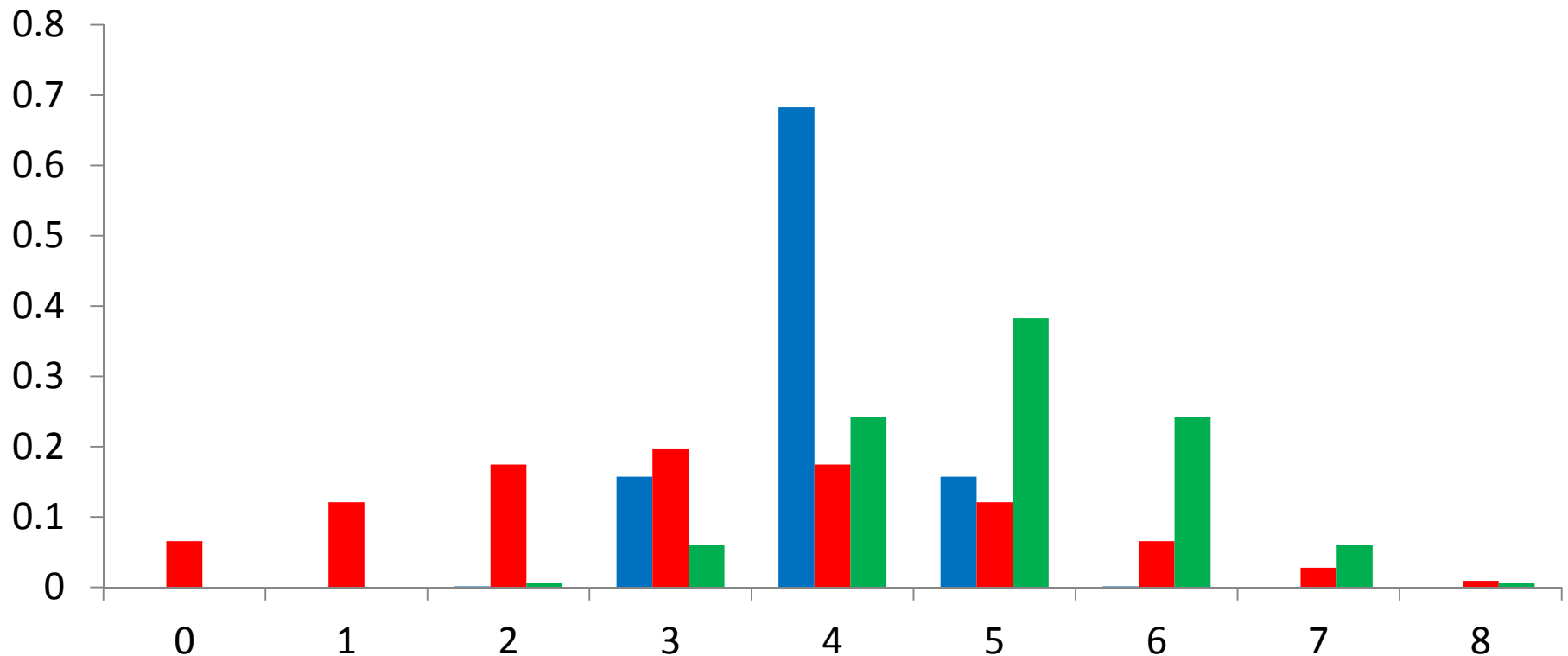
- Often scientists use smooth curves called **probability distributions** to describe the shape of a bar graph.

### Exercise 3c: Visualizing measures of central tendency & spread

- ❑ One type of probability distribution is called a **normal distribution**.
- ❑ Normal distributions are very important because, as the name implies, they are considered to be the most standard type of distribution.
- ❑ When scientists examine data, one of the first questions they ask is whether the data are normally distributed. Below is a plot of several normal distributions. Note that although these distributions vary, they all have the same basic shape.



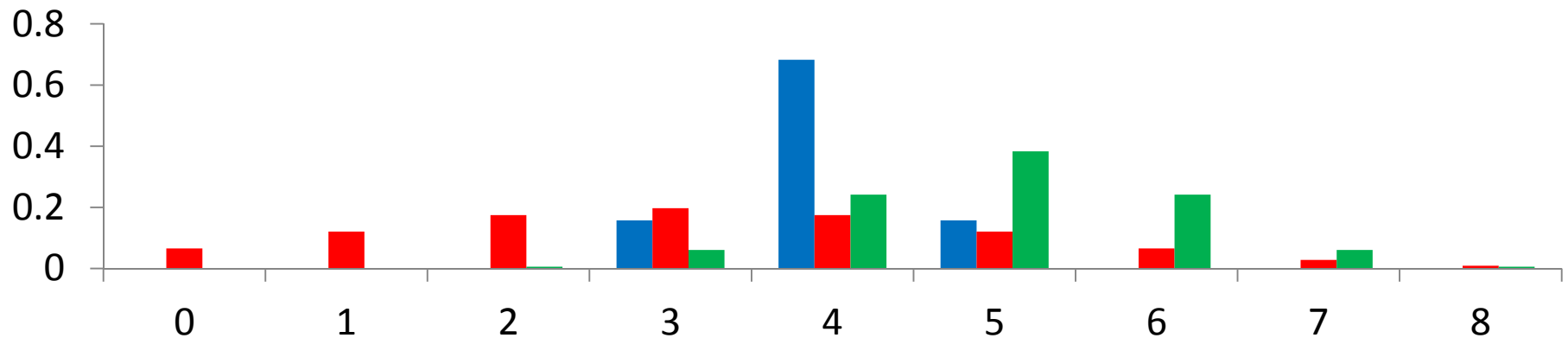
## Exercise 3c: Visualizing measures of central tendency & spread



**Q12:** The figure above shows three data sets that are normally distributed. How do their distributions differ? Do they have the same mean? Do they have the same variance? Which distribution has the greatest mean? Which distribution has the smallest variance?

**GO TO THE NEXT SLIDE FOR THE ANSWER!**

### Exercise 3c: Visualizing measures of central tendency & spread



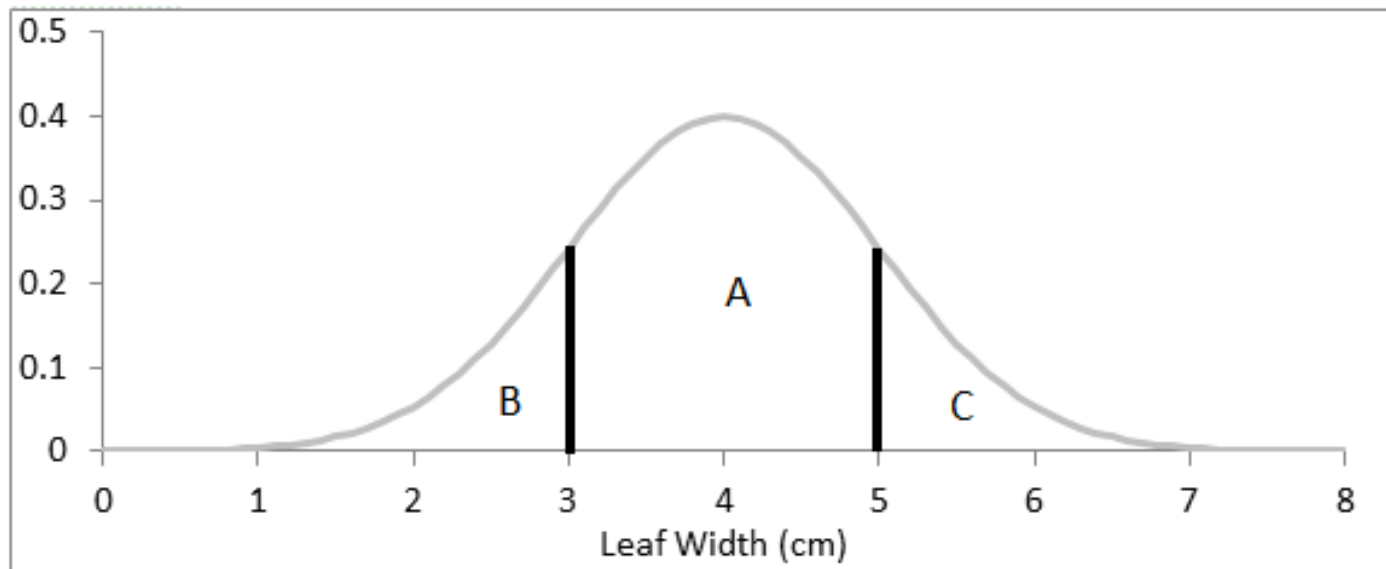
**Q12:** The figure above shows three data sets that are normally distributed. How do their distributions differ? Do they have the same mean? Do they have the same variance? Which distribution has the greatest mean? Which distribution has the smallest variance?

**CLICK FOR THE ANSWER!**

The green distribution has the greatest mean, and the blue distribution has the smallest variance.

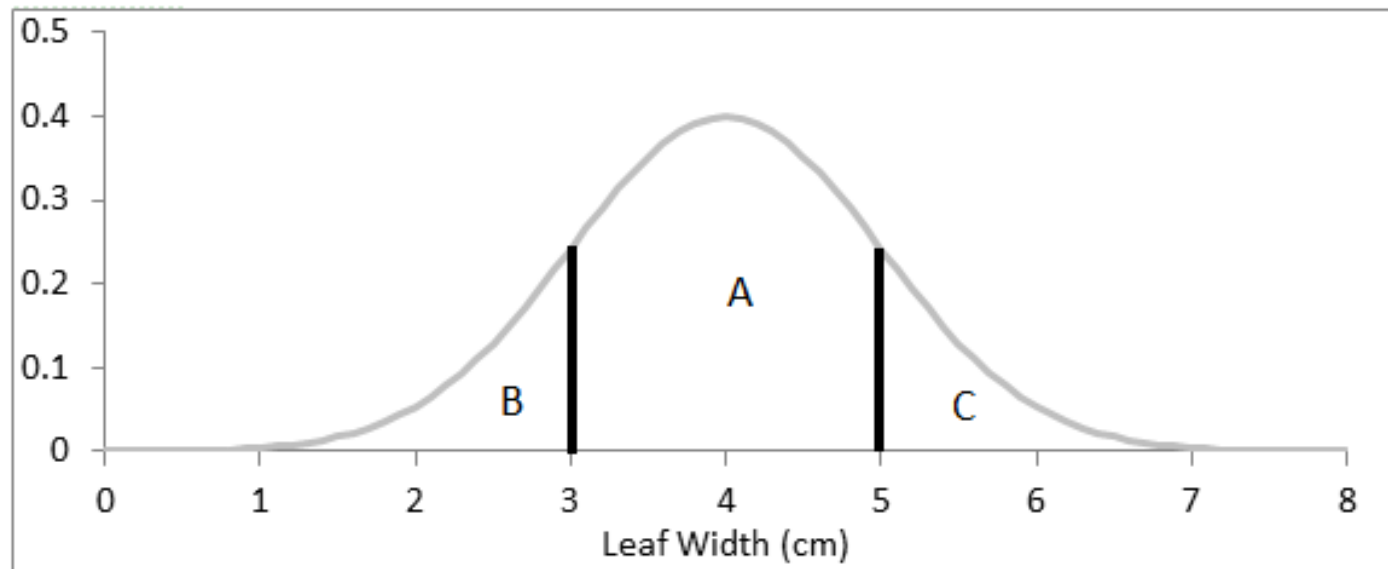
### Exercise 3c: Visualizing measures of central tendency & spread

- ❑ Probability distributions can also be used to find the probability that an individual has a range of trait values.
- ❑ The probability that an individual's trait value falls within an interval is equal to the area of the region bounded by the interval on the x-axis and the probability distribution curve. For example, assume that a trait is distributed according as in the figure below.
- ❑ The probability that an individual in the population has a trait value between 3 and 5 is equal to the area bounded by the two black line segments and the gray probability distribution curve (region A).



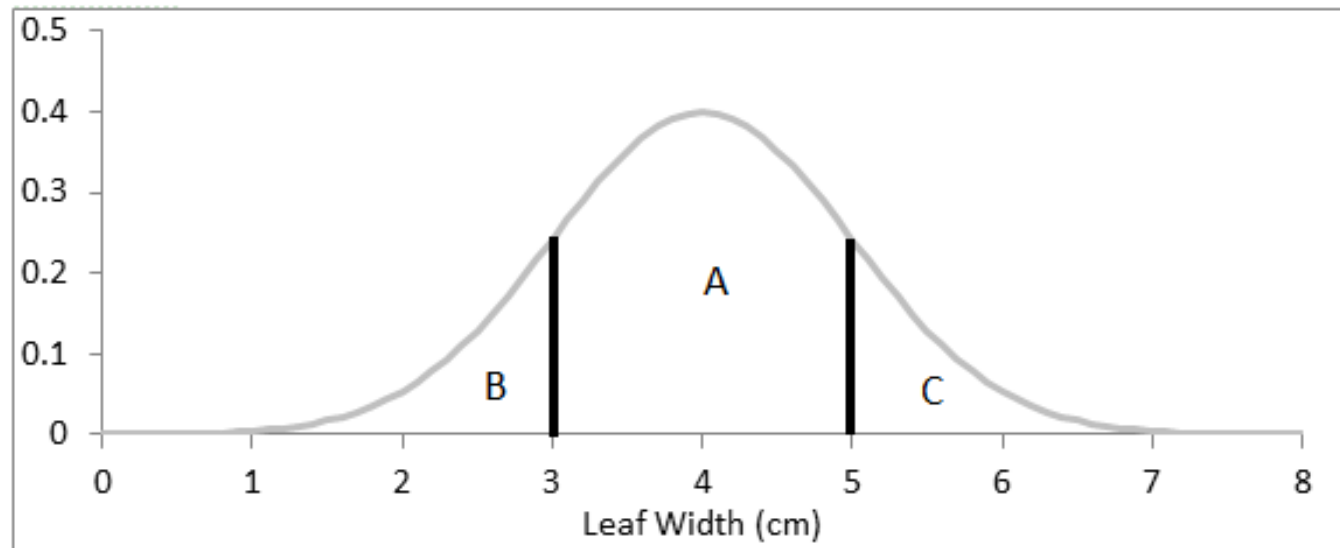
## Exercise 3c: Visualizing measures of central tendency & spread

- ❑ Probability distributions can also be used to find the probability that an individual has a range of trait values.
- ❑ The probability that an individual's trait value falls within an interval is equal to the area of the region bounded by the interval on the x-axis and the probability distribution curve. For example, assume that a trait is distributed according as in the figure below.
- ❑ The probability that an individual in the population has a trait value between 3 and 5 is equal to the area bounded by the two black line segments and the gray probability distribution curve (region A).





## Exercise 3c: Visualizing measures of central tendency & spread



❑ Use the figure above to answer the following questions:

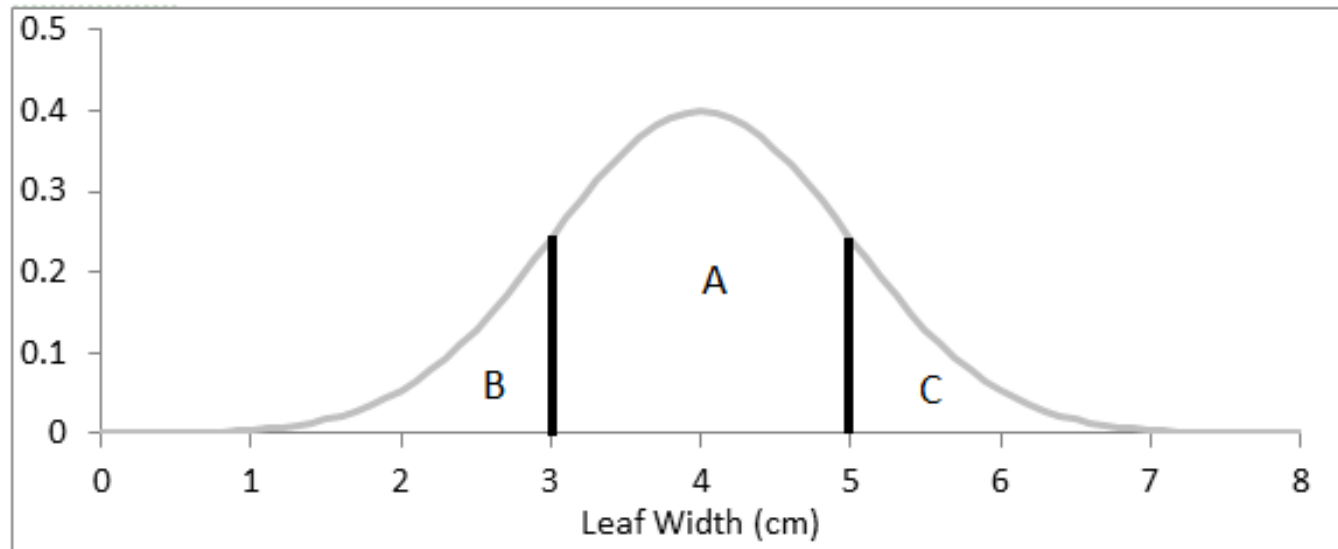
**Q13:** How can you interpret region C in terms of probabilities?

**Q14:** Now suppose that we select a leaf at random from the population. Rank the following events from most to least probable.

- a) The leaf's width is between 0 cm and 3 cm.
- b) The leaf's width is between 3 cm and 8 cm.
- c) The leaf's width is between 3 cm and 5 cm.

**GO TO THE NEXT SLIDE FOR THE ANSWERS!**

### Exercise 3c: Visualizing measures of central tendency & spread



**Q13:** How can you interpret region C in terms of probabilities?

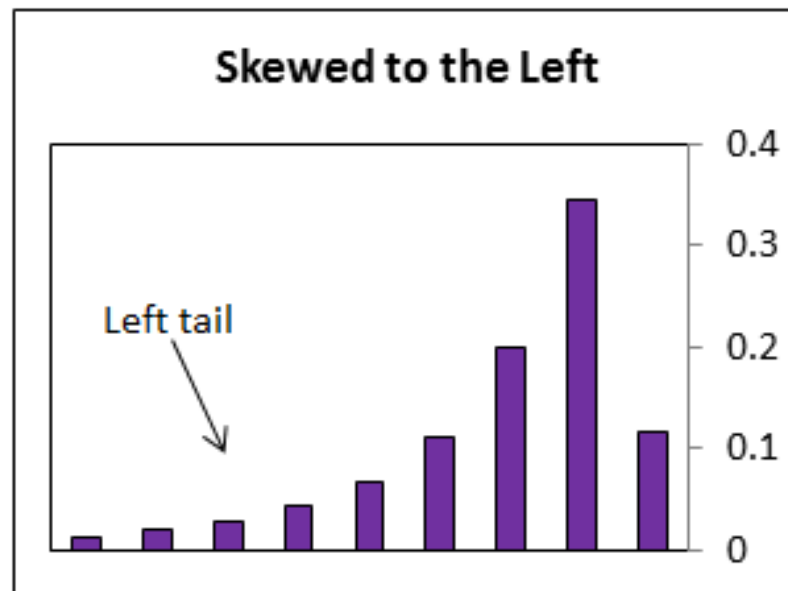
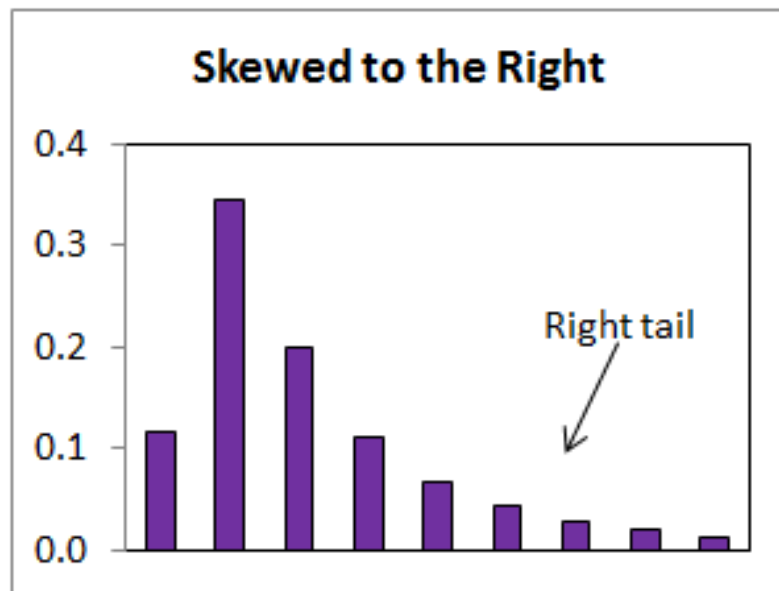
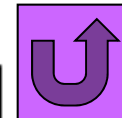
**The area of the region C represents the probability that a leaf drawn at random will have a leaf width greater than 5 cm.**

**Q14:** Now suppose that we select a leaf at random from the population. Rank the following events from most to least probable.

- a) The leaf's width is between 0 cm and 3 cm. **(2<sup>nd</sup> most probable)**
- b) The leaf's width is between 3 cm and 8 cm. **(most probable)**
- c) The leaf's width is between 3 cm and 5 cm. **(least probable)**

## Exercise 3c: Visualizing measures of central tendency & spread

- ❑ We can also use graphs to see if the data are skewed.



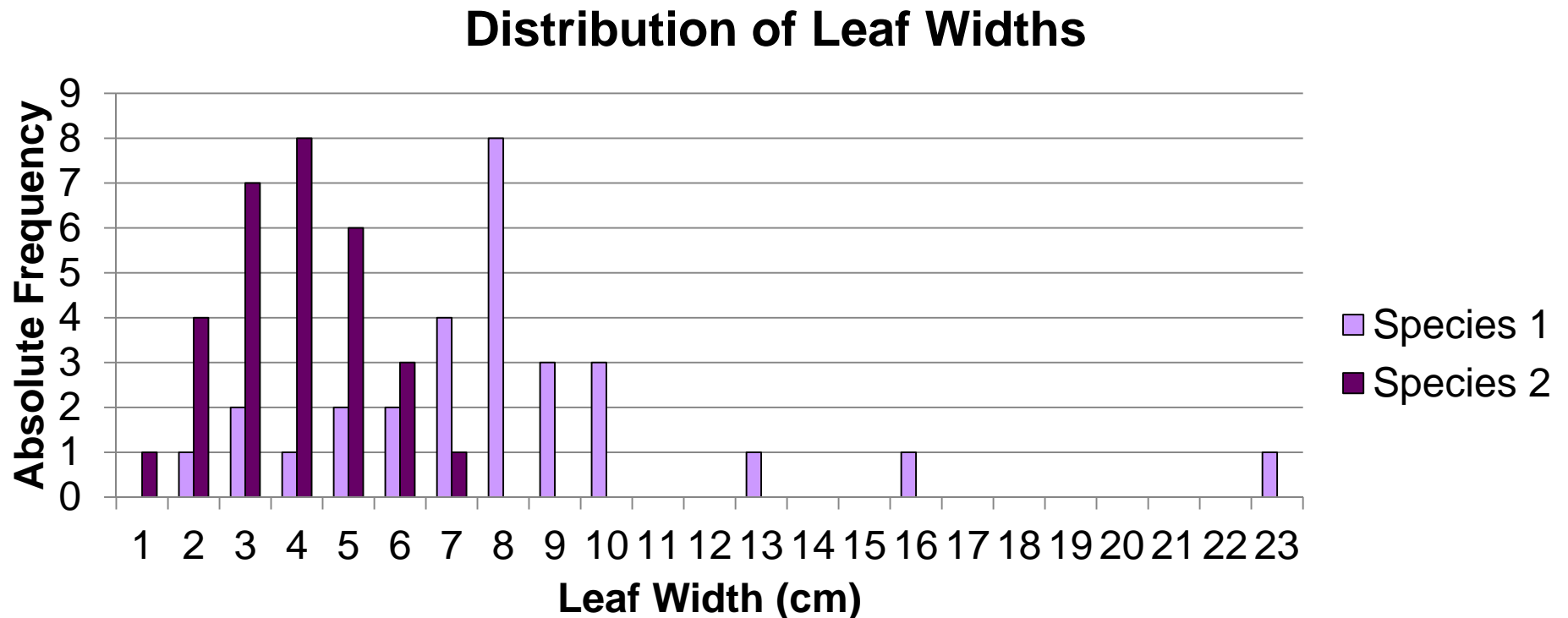
- ❑ Data are **skewed to the right** if the right tail of the graph is longer than the left tail of the graph.
- ❑ Similarly, the data are **skewed to the left** if the left tail of the graph is longer than the right tail of the graph.
- ❑ If a data set is normally distributed then it is not skewed, and it has only one mode, which is equal to its mean and its median.
- ❑ Make a bar graph of your leaf data. Is your graph skewed to the left or the right? Are your data normally distributed?

### Exercise 3d: Comparing leaves from two samples

- ☐ Find Container B, which contains two samples of leaves that were collected from two different species of trees or shrubs.
- ☐ Separate the leaves according to which sample they belong to (species A or species B).
- ☐ Have each student select one leaf from each sample and measure the selected trait.
- ☐ For each sample, order the measurements and construct a frequency table as you did in Exercise 3a. Compute the mean, median, mode, range, and variance for both samples and make a double bar graph to help you compare how the different samples are distributed.

### Exercise 3d: Comparing leaves from two samples

**Q15:** Examine the figure below. Which species appears to have narrower leaves? Which species appears to have a broader leaf width distribution?



**CLICK FOR THE ANSWER!**

**Species 2 appears to have narrower leaves. Species 1 appears to have a broader leaf width distribution.**

### Exercise 3d: Comparing leaves from two samples

- ☐ Now use your bar graph to answer the following questions about species A and species B provided in this unit.
- ☐ Do you think that one of these trees has larger leaves on average? Why or why not?
- ☐ Do you think that one of these trees has a broader distribution of leaf widths? Why or why not?
- ☐ Now use your statistics to answer the same questions again. Did your answers change?
- ☐ Add the samples' means, medians, and modes to the label of the x-axis of your graph.

### Exercise 3d: Comparing leaves from two samples

- ☐ Often scientists compare populations to see if they are different.
- ☐ In particular, scientists are often interested in comparing the means of two populations.
- ☐ This is no easy task, because, as we have already mentioned, it is not usually possible to measure a population as a whole.
- ☐ Usually scientists are only able to measure a sample of the population. So, instead of comparing the population means scientists are forced to compare sample means.
- ☐ Because samples are incomplete and imperfect representations of the populations from which they are drawn, the sample mean is only an estimate of the population mean.
- ☐ Therefore, sometimes it happens that two samples may have different means, while the populations from which they were drawn have the same mean.
- ☐ Alternatively, the sample means may be the same, though the population means may actually be different.

### Exercise 3d: Comparing leaves from two samples

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



### Exercise 3d: Comparing leaves from two samples

- ❑ Let's say, for example, that you think there is a difference in average height of American high school baseball players and high school soccer players.
- ❑ The **alternative hypothesis** (often represented as  $H_A$  or  $H_1$ ) is simply the original hypothesis formulated by the scientist.
- ❑ For example, there is a difference between the average heights of American high school baseball players and high school soccer players. This would be your alternative hypothesis in this case.
- ❑ The **null hypothesis** (often represented as  $H_0$ ) is essentially a hypothesis that is one that opposes your alternative hypothesis.
- ❑ In our example, the null hypothesis in this case would be that there is NO difference in the average heights of American high school baseball players and high school soccer players.

### Exercise 3d: Comparing leaves from two samples

- ❑ Null and alternative hypotheses can also have directionality. For example, if you think that baseball players are TALLER than soccer players, the hypotheses you would be testing would be as follows:
  - ❑  $H_0$ : American high school baseball players are shorter than, or equal in height to American high school soccer players on average.
  - ❑  $H_A$ : American high school baseball players are taller than American high school soccer players on average.
- ❑ As already mentioned, the populations of interest in this example are way too large for you to measure the height of every player.
- ❑ So, you could collect data (ideally by randomly sampling) the populations. For example, you could travel to randomly determined high schools, and measure as many randomly selected players as time and money would allow. You would then have a set of sample data, which you could use to statistically test your hypothesis.

### Exercise 3d: Comparing leaves from two samples

- ❑ In conducting statistical hypothesis tests, it is important to realize that what you are doing, **ALWAYS**, is really testing, based on the sample data, whether you should reject or “fail to reject” the **NULL HYPOTHESIS**.
- ❑ Scientists prefer to say that they “fail to reject” a null hypothesis when doing so is supported by their data, rather than saying they “accept” it, as accepting it implies that the null hypothesis is completely true.
- ❑ However, they know that this very well may not be the case. The null hypothesis may be false, but they may not have enough data to conclusively show that it is false!)
- ❑ There are many different types of statistical tests, each of which are used for various types of data, but they all follow the same basic idea.
- ❑ The next slide provides an overview of the general procedure for all statistical tests.

## Exercise 3d: Comparing leaves from two samples

### General steps of all statistical tests:

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

### Exercise 3d: Comparing leaves from two samples

- ☐ So, how do scientists make informed decisions on population means based only on sample means?
- ☐ Such decisions are based around the concept of **significance**.
- ☐ In other words, if two sample means are different, how likely is it that the difference between those sample means actually reflects a difference in the means of the entire populations in question?
- ☐ Let's return to our example of the average heights of American high school baseball players and American high school soccer players, but first let's talk a little bit about the types of errors that can be made in statistical tests.

### Exercise 3d: Comparing leaves from two samples

- ❑ Remember, very often in science, it is impossible to be 100% certain about populations in which we are interested, simply because we cannot measure every individual in the populations. Because of this, there are two different types of errors that we could make based on our data:
  - ❑ We could incorrectly reject the null hypothesis when it is true. This is called a **Type I error**.
  - ❑ We could incorrectly fail to reject the null hypothesis when it is false, which is known as a **Type II error**.

### Exercise 3d: Comparing leaves from two samples

- ❑ Remember, these are the types of errors one can make when conducting statistical tests:
  - ❑ **Type I error**: Incorrectly rejecting a true  $H_0$ .
  - ❑ **Type II error**: incorrectly failing to reject a true  $H_0$ .
- ❑ Dealing with Type II errors is easily solved by gathering as much data as possible.
- ❑ If our sample sizes are large, we are more likely to detect real differences that exist between populations based on our samples.
- ❑ But, how do we deal with Type I errors?
- ❑ In other words, how do we keep from failing to reject a null hypothesis that is actually true?

## Exercise 3d: Comparing leaves from two samples

### ☐ Review of types of statistical errors:

☐ **Type I errors:** Incorrectly rejecting a true  $H_0$ .

☐ **Type II error** incorrectly failing to reject a true  $H_0$ .

- ☐ Scientists deal with Type I errors by deciding how sure they want to be (usually 95%, sometimes 99%; remember, we can never have 100% certainty!) that they are correct in their decision to *reject* the null hypothesis.
- ☐ The value representing the remaining margin of uncertainty (5% or 1%, usually represented in decimal forms as probabilities of 0.05 or 0.01) is known as the **significance level** of the test.
- ☐ This is directly related to our earlier discussion of the meaning of significance, in that the more certain we wish to be that our decision to reject the null hypothesis is correct, the larger the differences between our samples from the populations of interest (relative to the variances) have to be in order for them to be considered **significant**.



### Exercise 3d: Comparing leaves from two samples

- ❑ If you find that, in your samples, the baseball players are an average of  $\frac{1}{4}$ " taller, is this really significant?
- ❑ Such a small difference may be accounted for by some of the soccer players slouching while being measured, or differences in the thickness of the soles of shoes of any of the players.
- ❑ Such a small difference could also be a matter of error in your measurements, as perhaps not all of your measurements were done exactly the same way.
- ❑ Thus, chance or error could account for such a small difference, and baseball players may not really be taller than soccer players after all!
- ❑ However, if your sample means indicated that baseball players are 6" taller than soccer players, this difference is likely to be a real one, because such a difference is likely too large to be accounted for by chance or error.

### Exercise 3d: Comparing leaves from two samples

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

### Exercise 3d: Comparing leaves from two samples

- ❑ Let's return to our baseball/soccer player example. If the difference in sample mean heights was very small, our confidence to say that the population mean heights are different is lower than it would be if the difference in sample mean heights was fairly large.
- ❑ Also, let's say we only measured 10 baseball players and 10 soccer players. Those are fairly small samples.
- ❑ What if the baseball sample, just by chance, contained 2 boys much taller than the average baseball player, or our soccer sample contained a much shorter than average player?
- ❑ Either of these increases the chances that our results are not significant. However, if we measured 100 players of each sport and obtained the same difference in sample means, we would be more confident that such a height difference is significant.
- ❑ Nevertheless, the greater the difference between sample means, the more likely the population means are also different!

### Exercise 3d: Comparing leaves from two samples

- ❑ However, the significance of the difference between sample means also depends on the variance of the samples.
- ❑ **In general, the larger the sample variances, the less likely it is that the difference in the sample means is significant.**
- ❑ In order to understand how the variance affects the significance of the difference in the means, we will look at an example.

### Exercise 3d: Comparing leaves from two samples

- ❑ Suppose that a scientist is studying how leaf width varies with rainfall in two plant species, fire bushes (FB) & maple trees (MT).
- ❑ He collects four sets of leaf samples representing the two species, each found at the same two localities that differ in annual rainfall.
- ❑ Both localities were suburban yards, but locality 1 (L1 in east TN) receives 48 inches of rainfall a year and locality 2 (L2 in Fort Lauderdale, FL), 64 inches of rainfall per year.

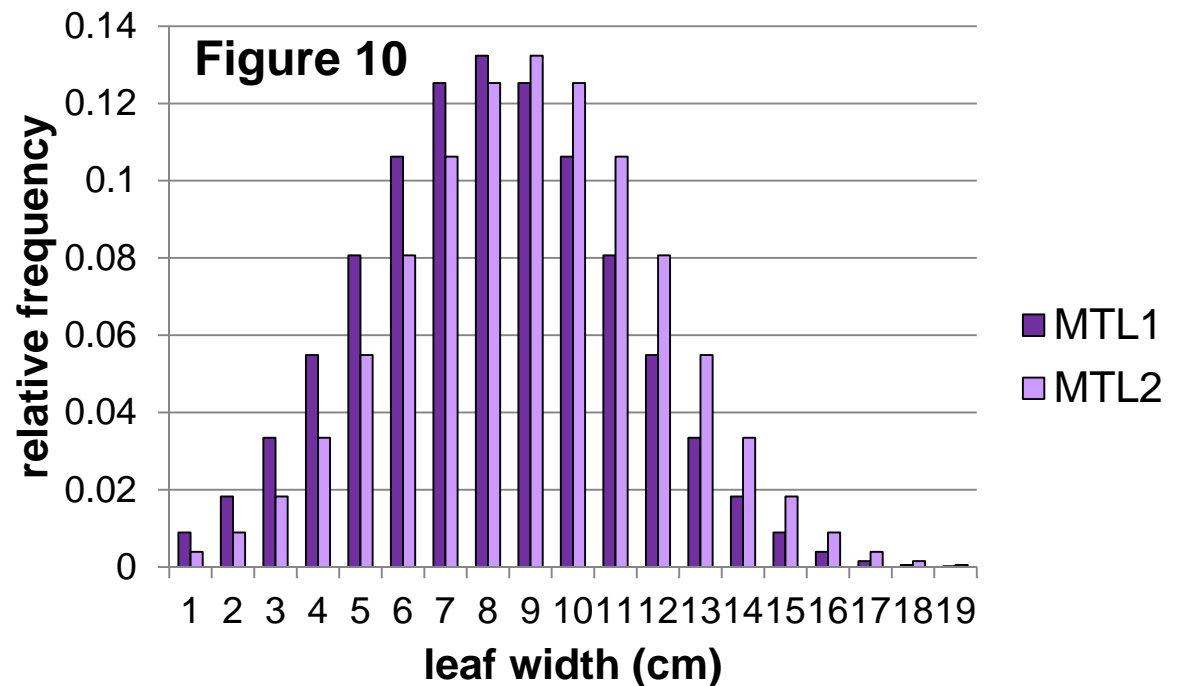
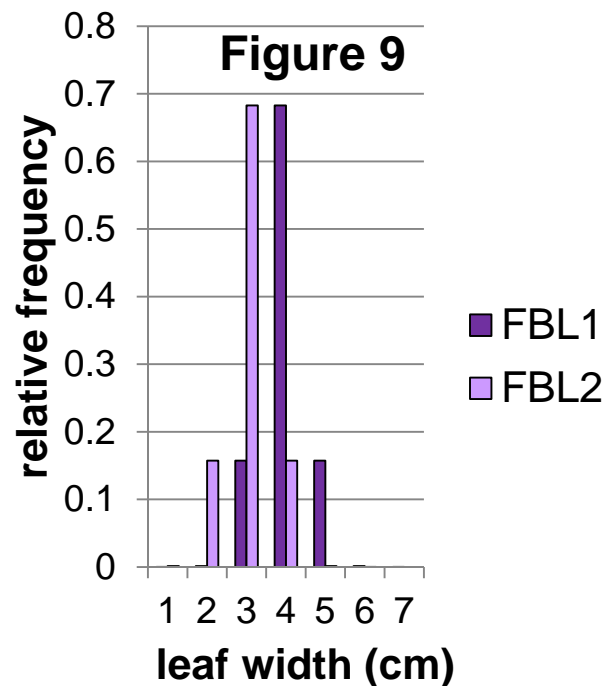
**Q17:** Assuming that a large number of leaves were collected from all of the trees at the respective localities, which of the following best describes the population to which MTL1 belongs?

- a) All of the maple leaves in North America
- b) All of the maple leaves from suburban yards
- c) All of the maple leaves found at the locality L1
- d) All of the maple leaves that receive approximately 48 inches of rainfall a year

**CLICK FOR THE ANSWER!**

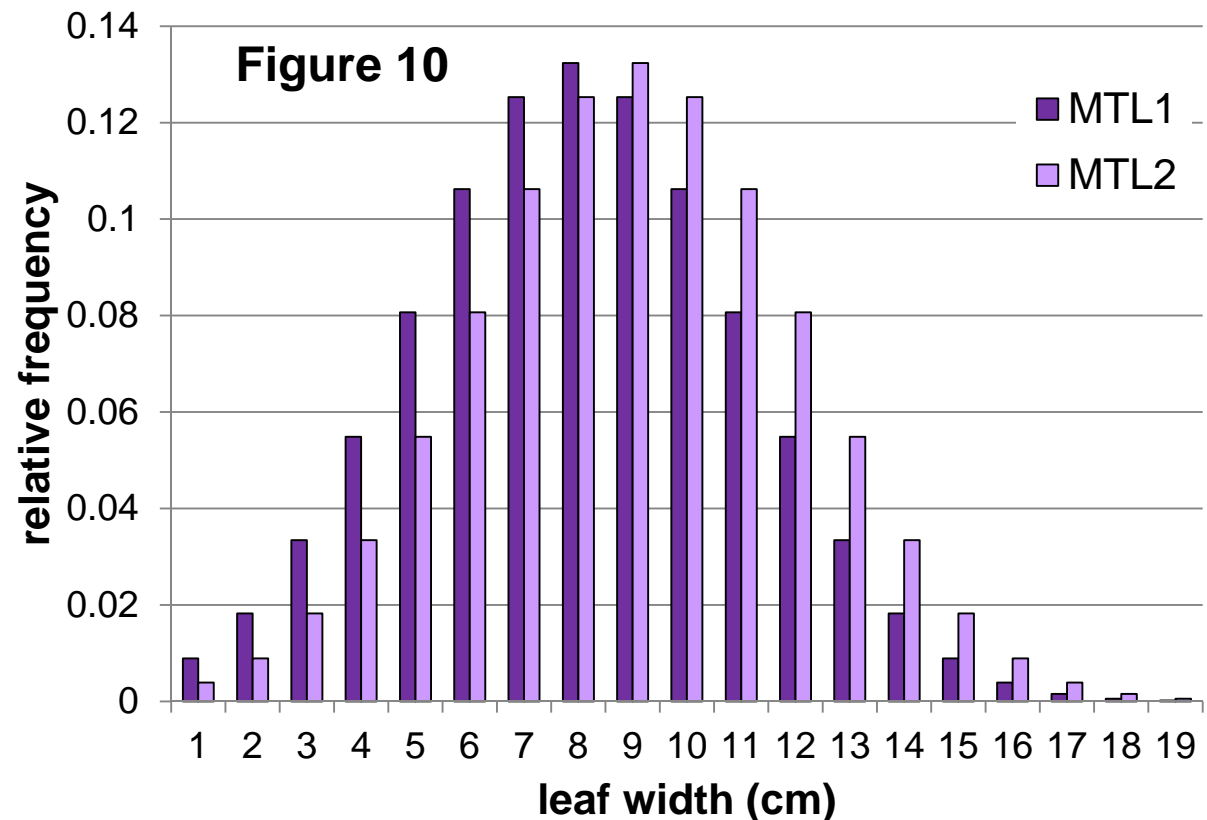
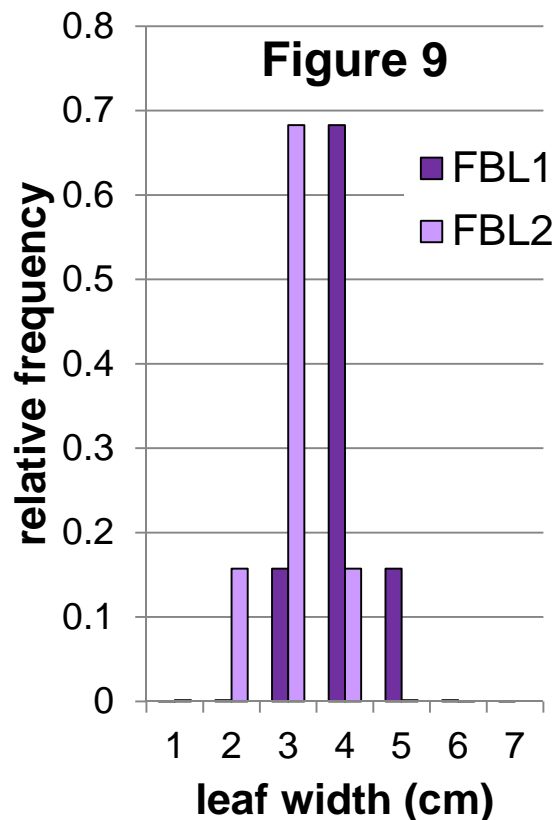
## Exercise 3d: Comparing leaves from two samples

- ❑ Look at Figures 9 and 10. Figure 9 shows the distribution of leaf widths in samples FBL1 and FBL2. Figure 10 shows the distribution of leaf widths in samples MTL1 and MTL2.
- ❑ Populations represented by these samples are normally distributed.
- ❑ Also, the populations from which FBL1 & FBL2 were taken have the same variance, as do the populations from which MTL1 and MTL2 were taken.



## Exercise 3d: Comparing leaves from two samples

- ❑ Use Figures 9 and 10 and your knowledge of normal distributions to answer the following questions.



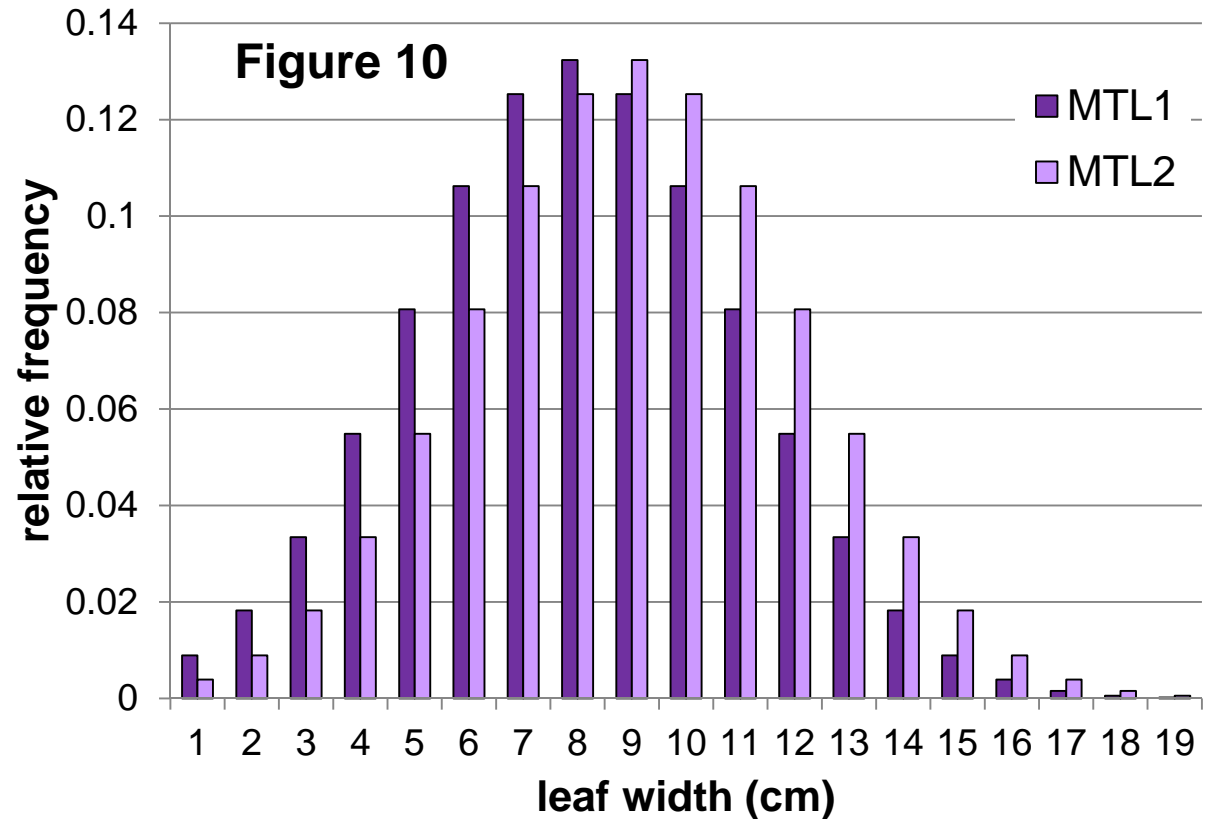
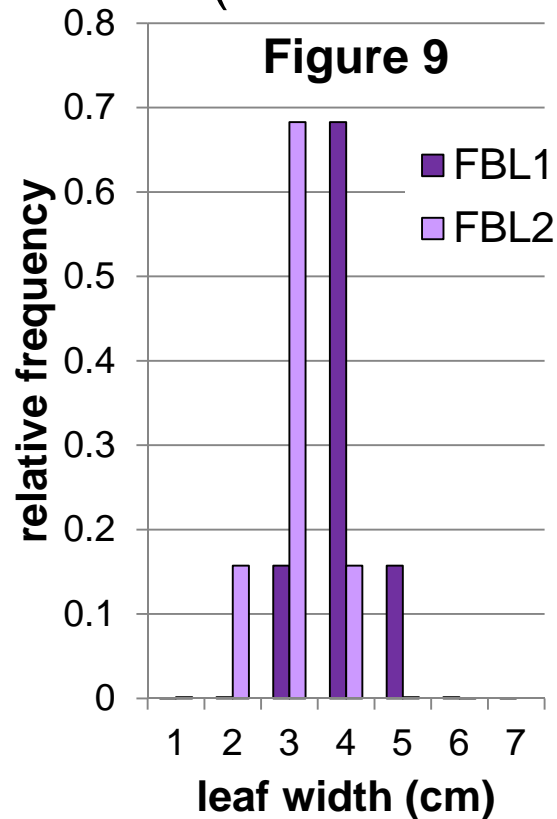
**Q18:** What are the means of FBL1, FBL2, MTL1, and MTL2?

**CLICK FOR THE ANSWER!**

FBL1: Mean = 4; FBL2: Mean = 3; MTL1: Mean = 8; MTL2: Mean = 9

## Exercise 3d: Comparing leaves from two samples

**Q19:** What is the difference between the means of FBL1 & FBL2 (FBL2-FBL1)? What is difference between the means of MTL1 & MTL2 (MTL2-MTL1)?



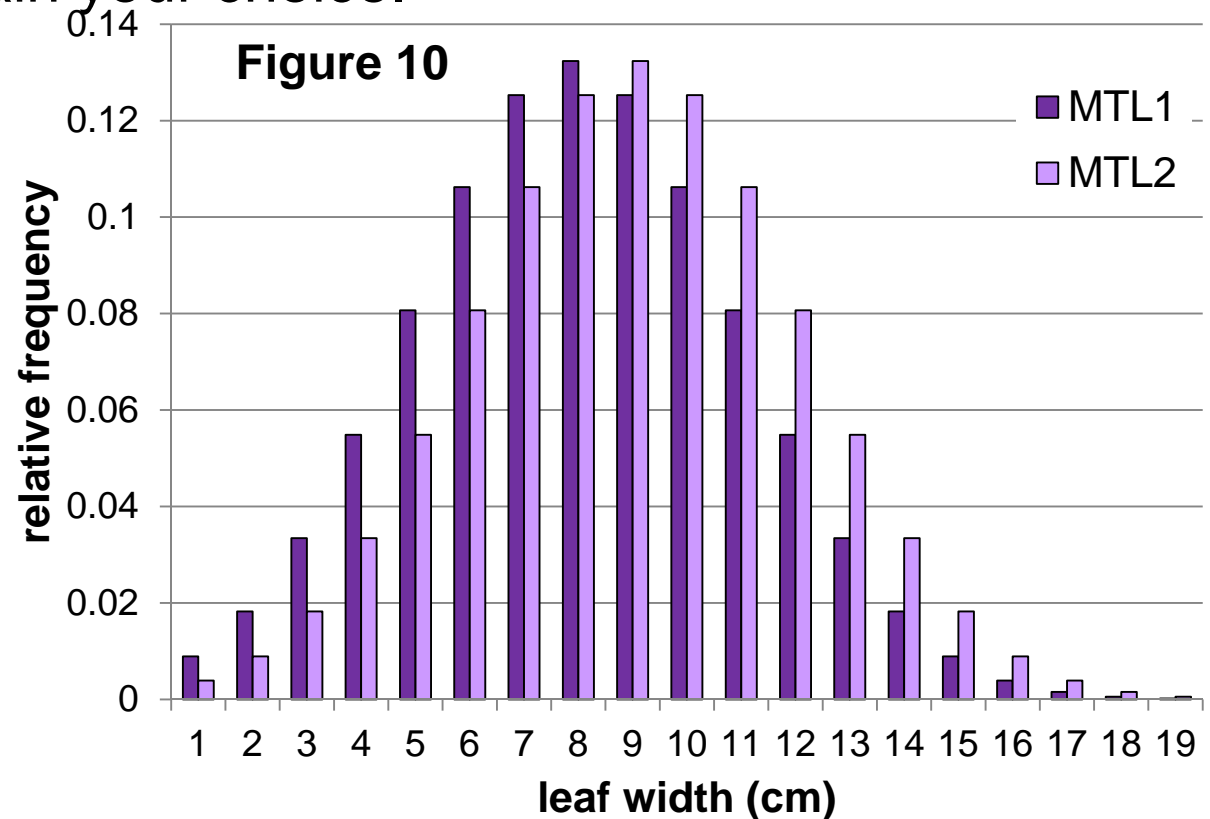
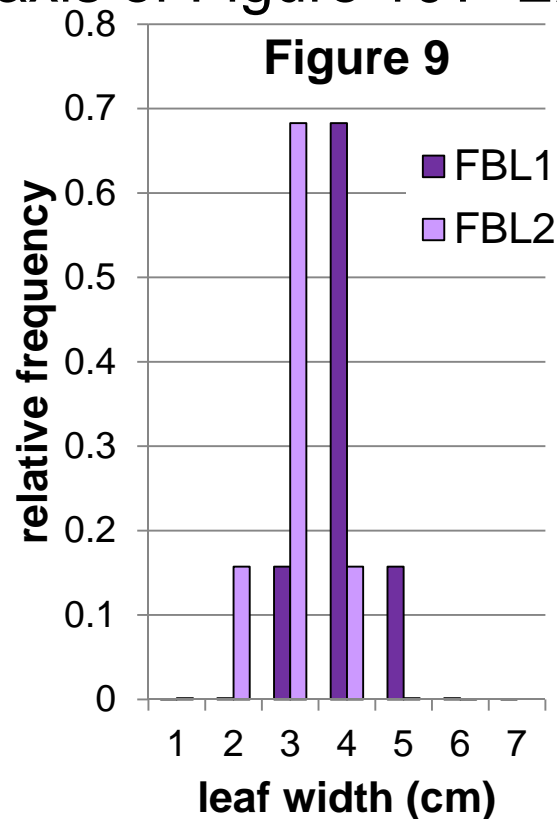
**CLICK FOR THE ANSWER!**

- ☐ The difference between the means of FBL1 & FBL2 is equal to 1.  
The difference between the means of MTL1 & MTL2 is also 1.



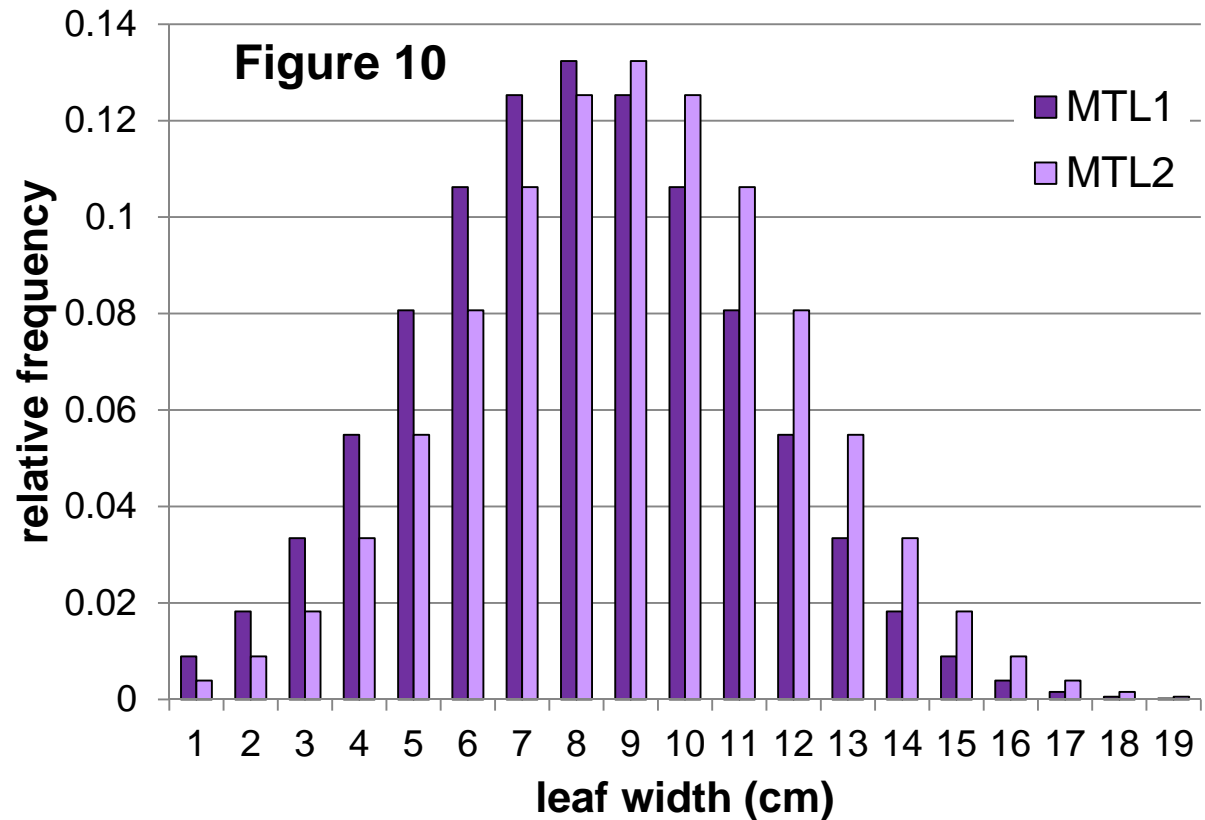
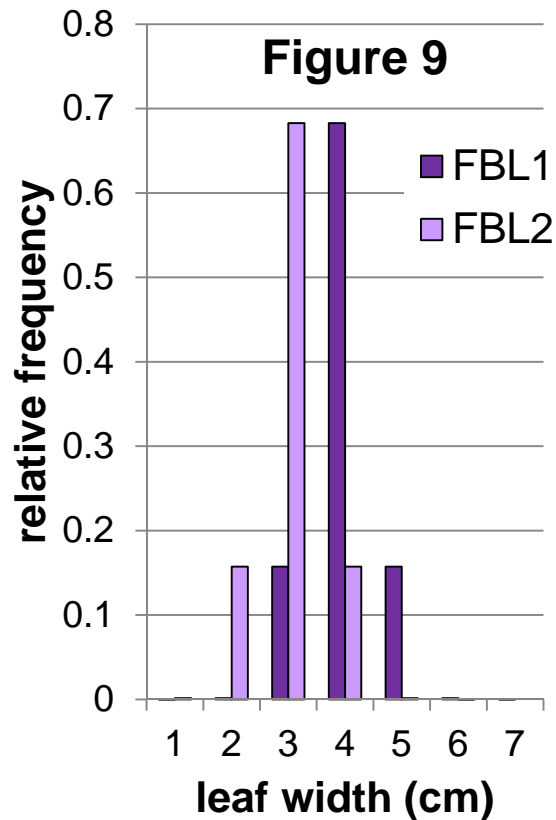
## Exercise 3d: Comparing leaves from two samples

**Q20:** Compare the x-axis of Figure 9 to the x-axis of Figure 10. Which difference appears to be more significant, the difference between the means of FBL1 and FBL2 along the x-axis of Figure 9, or the difference between the means of MTL1 and MTL2 along the x-axis of Figure 10? Explain your choice.



**GO TO THE NEXT SLIDE FOR THE ANSWER!**

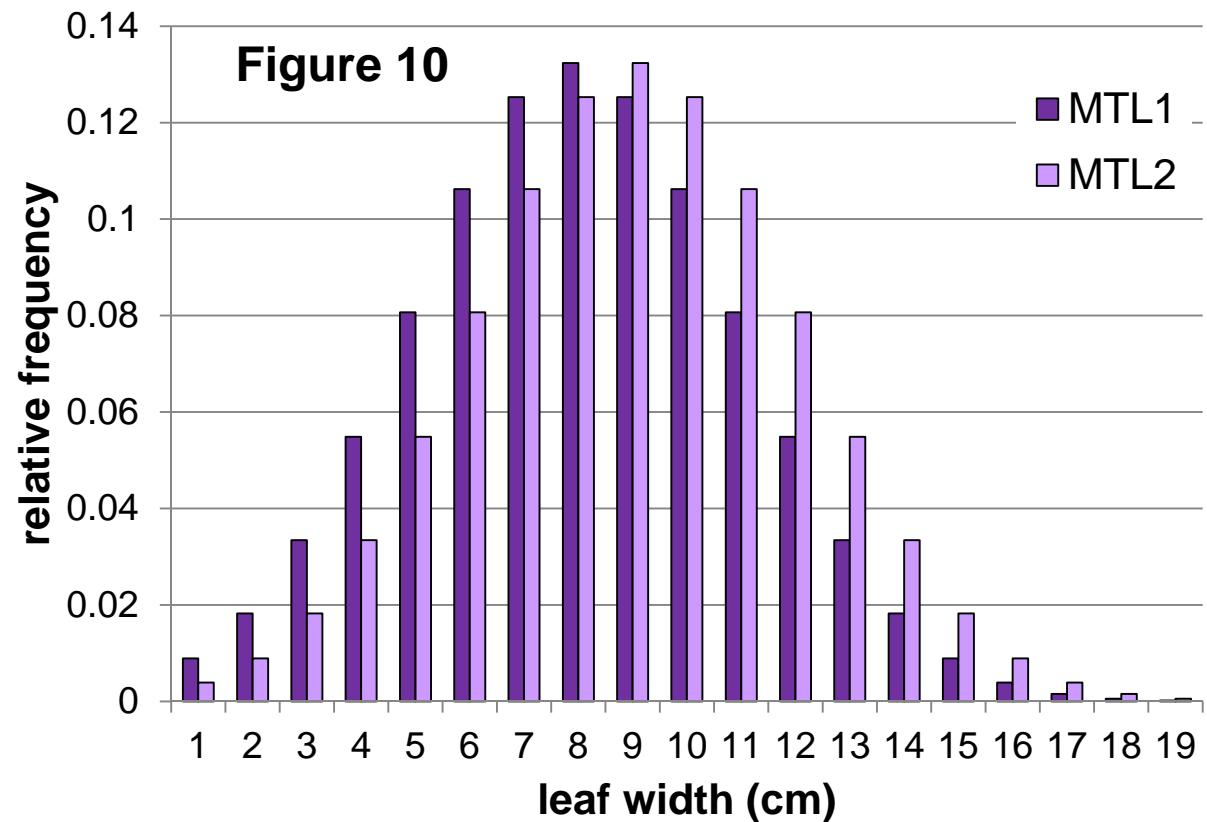
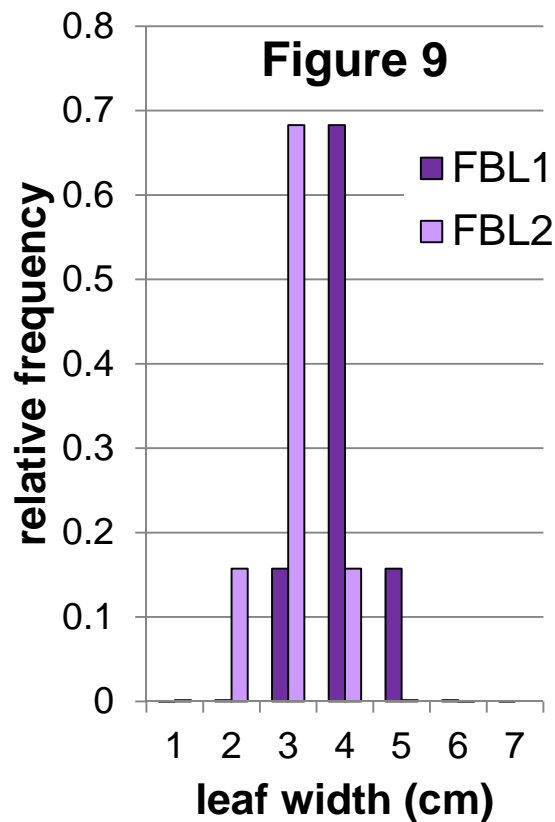
## Exercise 3d: Comparing leaves from two samples



In these figures, the difference between the means of MTL1 & MTL2 *appears* to be more significant because the distance between the mean of FBL1 and the mean of FBL2 is longer than the distance between the mean of MTL1 and the mean of MTL2. However, this may not necessarily be true. Go on to the next questions to further explore the significance of the differences.

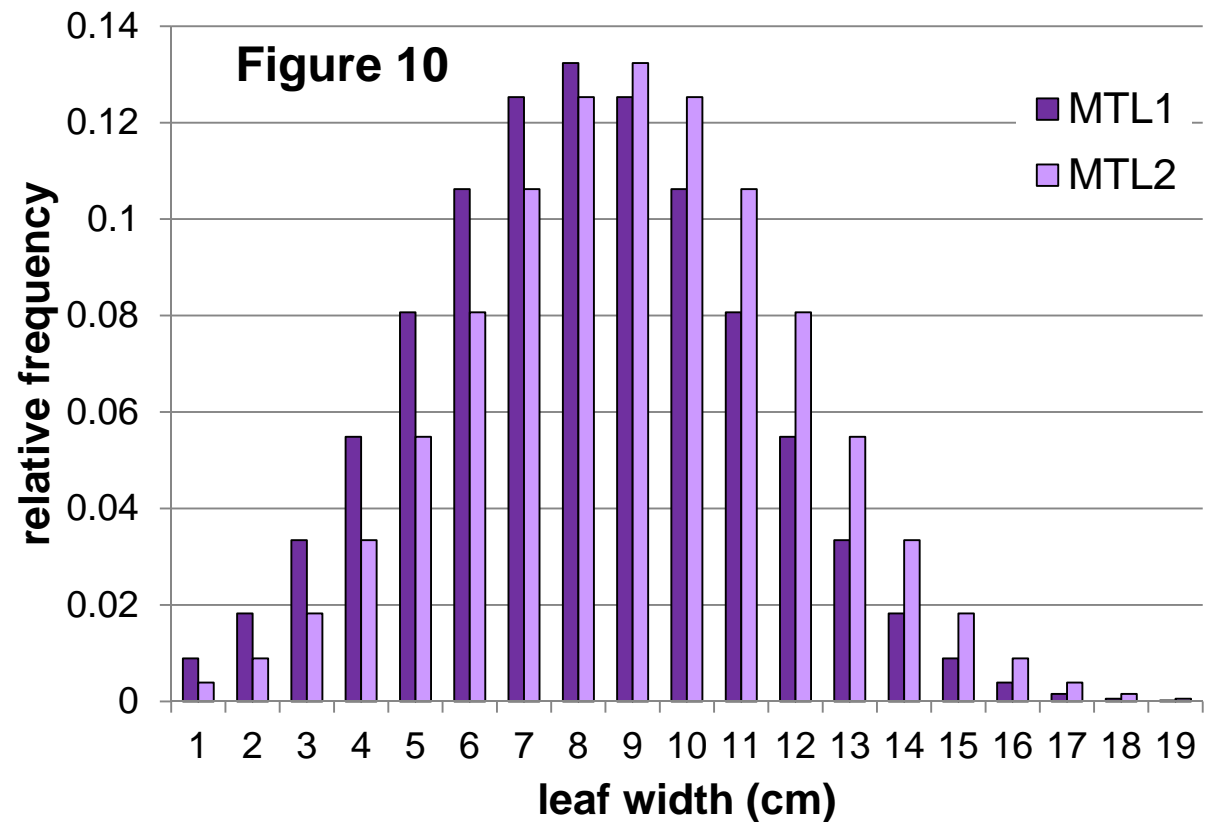
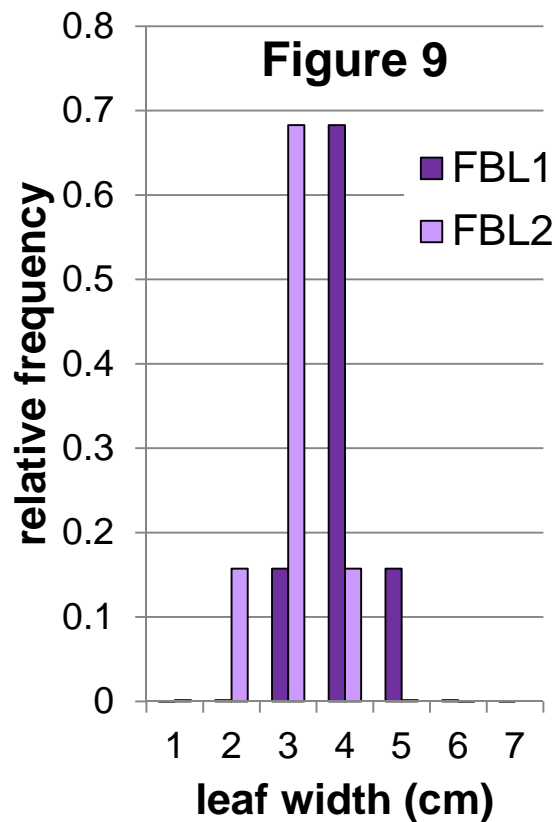
## Exercise 3d: Comparing leaves from two samples

**Q21:** Thinking about the influence of variance on the significance of the difference between sample means, what is another method, using a ruler, you could use to evaluate the significance of the differences in the comparisons in Figures 9 & 10? (**HINT: Think about the differences between sample means relative to the variances!**) **GO TO THE NEXT SLIDE FOR THE ANSWER!**



## Exercise 3d: Comparing leaves from two samples

**Q21:** Thinking about the influence of variance on the significance of the difference between sample means, what is another method, using a ruler, you could use to evaluate the significance of the differences in the comparisons in Figures 9 & 10? (**HINT: Think about the differences between sample means relative to the variances!**) **GO TO THE NEXT SLIDE FOR THE ANSWER!**



### Exercise 3d: Comparing leaves from two samples

**Q21:** Thinking about the influence of variance on the significance of the difference between sample means, what is another method, using a ruler, you could use to evaluate the significance of the differences in the comparisons in Figures 9 & 10? (**HINT: Think about the differences between sample means relative to the sample variances!**)

**CLICK FOR THE ANSWER!**

- ☐ Using a ruler, you could measure the distances between the sample means in each figure.
- ☐ However, keeping in mind the importance of sample variances (reflected by the total span of the x-axis in each figure), you would also want to measure the length of the x-axis in each figure, and calculate the proportion of the x-axis that is taken up by the distance between means in each figure.
- ☐ The greater this value, the greater the significance of the difference between the means compared in that particular figure.

### Exercise 3d: Comparing leaves from two samples

**Q22:** Using the method you came up with in the previous question, which comparison of sample means (FBL1 vs FBL2 or MTL1 vs MTL2) appears to be more significant? Why?

**CLICK FOR THE ANSWER!**

- ☐ Using the method from the previous question, you should see that the difference between the means of FBL1 and FBL2 takes up a greater proportion of the x-axis in Figure 9 than does the distance between the means of MTL1 and MTL2 relative to the x-axis in Figure 10.
- ☐ This means that the difference between the means of FBL1 and FBL2 is more significant than the difference between the means of MTL1 and MTL2, even though the magnitude of these differences is the same.
- ☐ In other words, for a given difference between means, the lower the variance, the greater the significance of the comparison.

## Comparing population means: the t-test

- ❑ In this exercise, you will actually use a statistical test, known as the **t-test**, to compare the average values of particular leaf traits of two different species of trees.
- ❑ You will be using data that you collect yourself, as well as calculating the **test-statistic**, and using this to help you make a decision regarding the appropriate null and alternative hypotheses.
- ❑ The **t-test** is frequently used to compare sample means to determine if the population means are likely to be different.

## How the t-test works

- ❑ The t-test uses the *sample* means to determine if the *population* means are likely to be different. It works if the following statements are true:
- ❑ The populations from which the samples were drawn are normally distributed.
  - ❑ *Remember, the larger a sample size, the more likely it is to have an approximately normal distribution. Therefore, this is why it's always a good thing to make your sample sizes as large as feasibly possible!*
- ❑ The populations from which the samples were drawn have the same variance.
  - ❑ *This is usually not a problem if the sample sizes are the same, or very close. This makes it important to have equal, or nearly equal sample sizes, in order for the t-test to be an appropriate one for your data!*



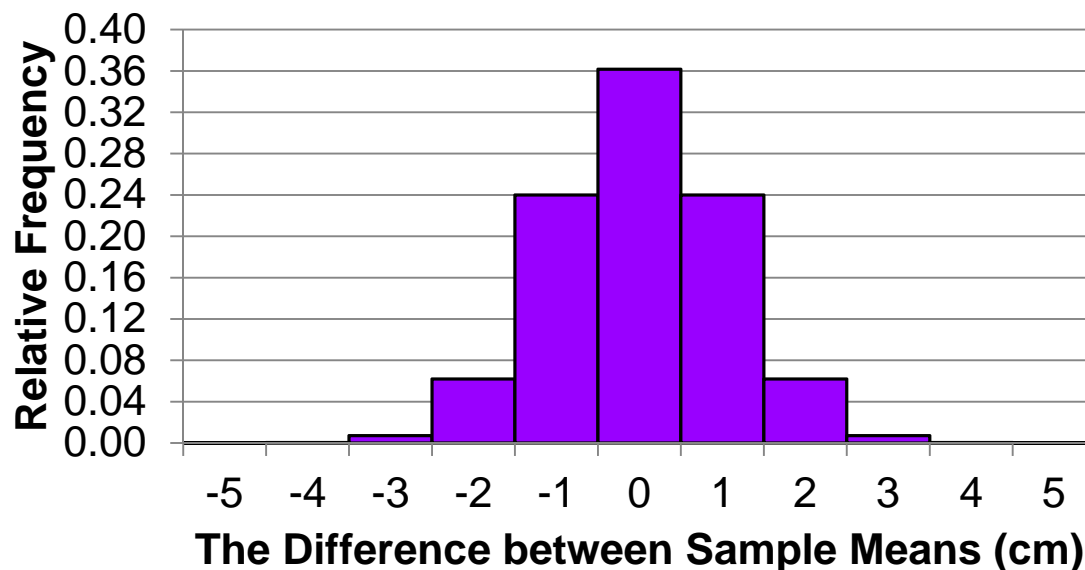
## How the t-test works

- ❑ When we perform the t-test we are essentially testing the following null hypothesis:
- ❑  **$H_0$ : The populations from which the samples were drawn have the same mean.**
- ❑ This is the hypothesis that we are testing, so at the beginning of the experiment, we don't know if it is true.

## How the t-test works

- ❑ Suppose two populations are normally distributed with the same mean and variance.
- ❑ Imagine that instead of sampling the populations just once, we sampled them thousands of times, & recorded the difference between the means each time (rounded to the nearest 0.5 cm).
- ❑ From these data, we made the relative frequency bar graph pictured below. This graph can be used to estimate the probability that the difference between sample means falls into a given range.

**The Relative Frequencies of  
Differences between Sample Means**

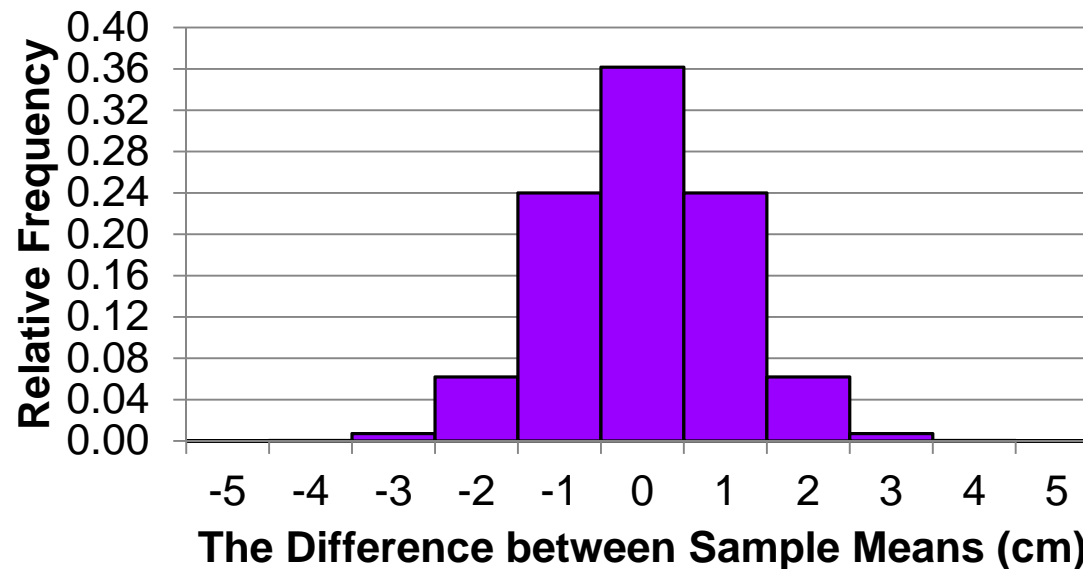


- ❑ For example, the probability that the difference between sample means is between 0.5 and 1.5 is about 0.24.

## How the t-test works

□ Use the graph below to answer the following questions:

**The Relative Frequencies of  
Differences between Sample Means**



**Q23:** What is the most likely value of the difference between sample means? Does this make sense? Why?

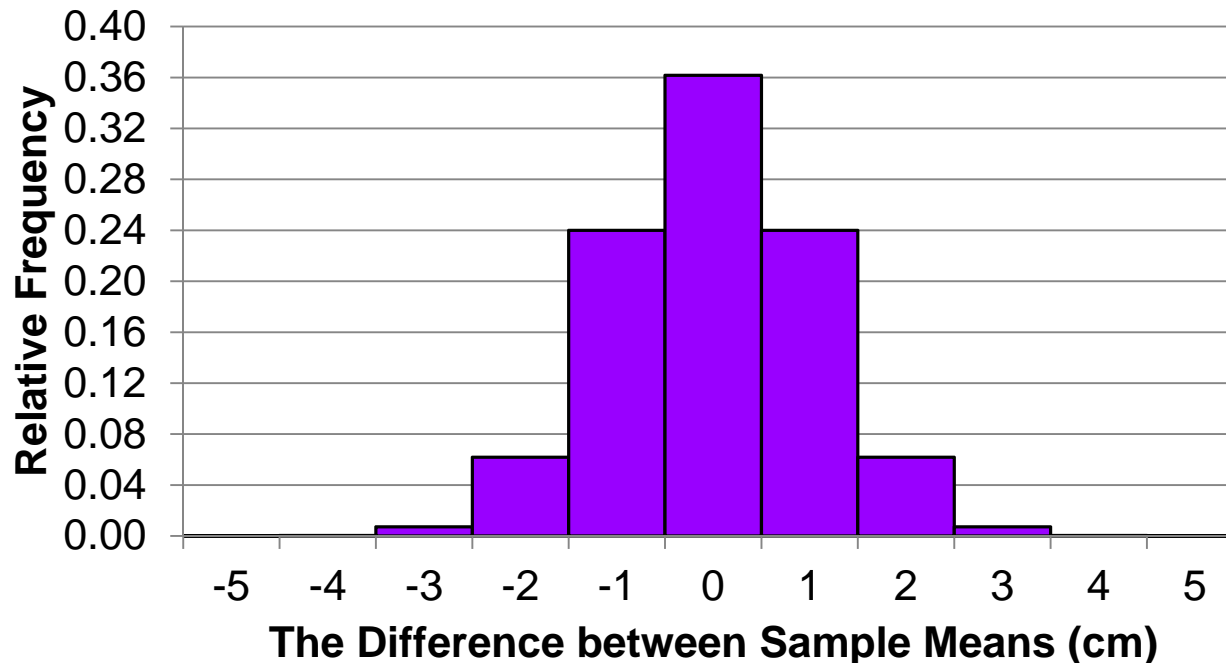
**CLICK FOR THE ANSWER!**

The sample difference is most likely to be close to zero. Since the populations from which the samples were drawn have the same mean, it makes sense that the samples are most likely to have similar means (with zero being the most likely value of the difference).

## How the t-test works

**Q24:** Estimate the probability that the difference between the sample means is greater than 2.5 cm. Is this event likely?

**The Relative Frequencies of Differences  
between Sample Means**



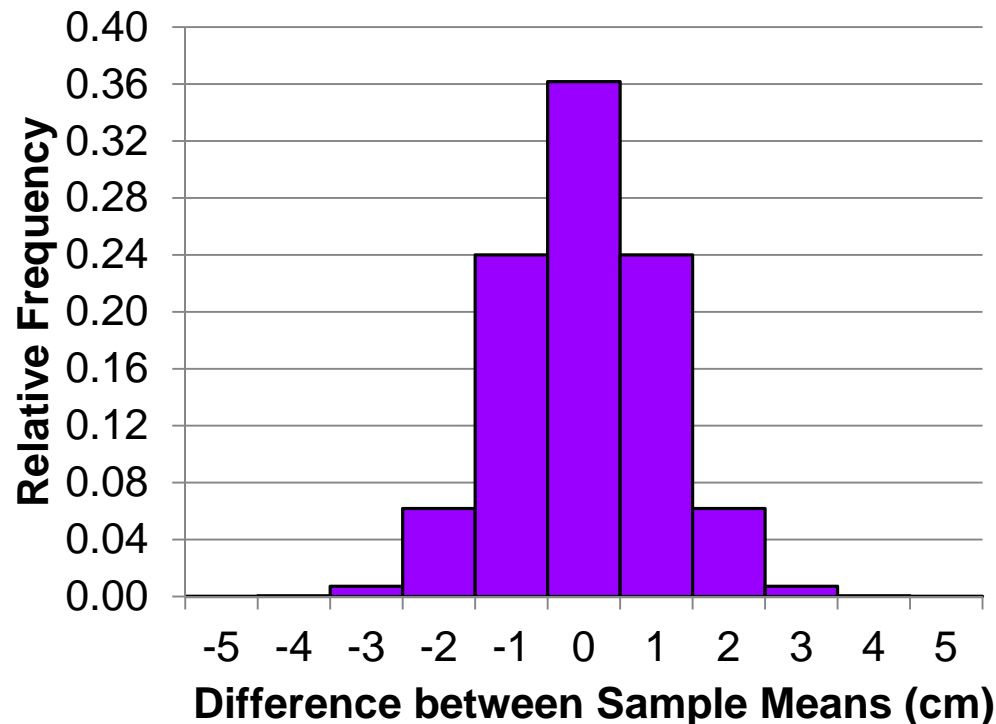
**CLICK FOR THE ANSWER!**

The probability that the difference in the sample means is greater than 2.5 is less than 0.01. This event is very unlikely.

## How the t-test works

**Q25:** Suppose that you sample two normally distributed populations with the same variance as the populations that we used to make the graph below. After computing the sample means you find that the difference between them is 3 cm. Do you think that these populations have the same mean? Why or why not?

**The Relative Frequencies of  
Differences between Sample  
Means**



**CLICK FOR THE ANSWER!**

These populations probably have different means because if they have the same mean, then the probability of drawing samples with such different means is very small, less than 0.01.

## How the t-test works

- ❑ The t-test works in the same way as the previous illustration, only there is no need to sample the populations thousands of times and create a relative frequency bar graph because the assumptions of the t-test *determine* the probability distribution that the difference in the sample means should follow.
- ❑ **The shape of this probability distribution depends on the population variances.**
- ❑ In particular, the difference in the means is more likely to be large for populations with larger variances.
- ❑ In order to eliminate the dependence of the probability distribution on the variances, we divide the difference in the means by a measure of the variances.
- ❑ This new quantity is called the **t-statistic**, and its probability distribution is called a **student's t distribution**.
- ❑ **The t-statistic may be positive or negative, but the larger its magnitude, the more likely it is that the difference between the means is significant.**

## How the t-test works

❑ The student's t-test for the comparison of two means uses the following quantities for species A and species B:

❑ *sample sizes* ( $n$ )

❑ *sample means* ( $\bar{x}$ )

❑ *sample variances* ( $s^2$ ; remember, these are our estimates of the *population variances!*)

❑ *standard deviations* ( $s$ ) that you found by taking the *square roots* of the variances.

❑ List these values on a sheet of paper for each of your species as follows:

$\bar{x}_A =$                        $s^2_A =$                        $n_A =$                        $s_A =$

$\bar{x}_B =$                        $s^2_B =$                        $n_B =$                        $s_B =$

## How to compute the t-statistic

- ❑ The t-statistic is a quotient.
- ❑ The numerator is the difference of the sample means and the denominator is a measure of the variance of the two samples.
- ❑ Below is an equation showing how the t-statistic is calculated **when the number of individuals in each sample are the same.**
- ❑ Let  $\bar{x}_A$  denote the mean of sample  $A$ ,  $\bar{x}_B$  denote the mean of sample  $B$ ,  $s^2_A$  denote the estimate of the variance of population  $A$ , and  $s^2_B$  denote the estimate of the variance of population  $B$ , and  $n$  denote the size of the samples (which is the same value for both samples). **The t-statistic is then computed as follows:**

$$t = \frac{\bar{x}_A - \bar{x}_B}{\sqrt{\frac{s^2_A + s^2_B}{n}}}$$



## How to compute the t-statistic

- ❑ If the sample sizes are not the same, then the formula for the t-statistic is a little more complicated.
- ❑ First, we will need to calculate the **pooled standard deviation** ( $s_{AB}$ ), before we can find it. If  $n_A$  is the size of sample  $A$ , and if  $n_B$  is the size of sample  $B$ , the pooled standard deviation is equal to

$$s_{AB} = \sqrt{\frac{s_A^2(n_A - 1) + s_B^2(n_B - 1)}{n_A + n_B - 2}}$$

The t-statistic is then calculated as follows:

$$t = \frac{\bar{x}_A - \bar{x}_B}{s_{AB} \sqrt{\frac{s_A^2}{n_A} + \frac{s_B^2}{n_B}}}$$

## How to compute the t-statistic

**Q26 (Super Solver Problem):** Show that the formula for the t-statistic with equal sample sizes is equivalent to the formula for the t-statistic with unequal sample sizes if  $n_A = n_B$ .

**CLICK FOR THE ANSWER!**

□ If  $n_A = n_B$  then we can substitute  $n_A$  for  $n_B$  in the equations for the pooled standard deviation and the t-statistic and simplify:

$$\begin{aligned} s_{AB} &= \sqrt{\frac{s_A^2(n_A-1) + s_B^2(n_A-1)}{n_A + n_A - 2}} \\ &= \sqrt{\frac{(s_A^2 + s_B^2)(n_A-1)}{2(n_A-1)}} = \sqrt{\frac{(s_A^2 + s_B^2)}{2}} \\ t \text{ statistic} &= \frac{\bar{x}_A - \bar{x}_B}{s_{AB} \sqrt{\frac{1}{n_A} + \frac{1}{n_A}}} \\ &= \frac{\bar{x}_A - \bar{x}_B}{\sqrt{\frac{(s_A^2 + s_B^2)}{2}} \sqrt{\frac{2}{n_A}}} = \frac{\bar{x}_A - \bar{x}_B}{\sqrt{\frac{s_A^2 + s_B^2}{n_A}}} \end{aligned}$$

## How to compute the t-statistic

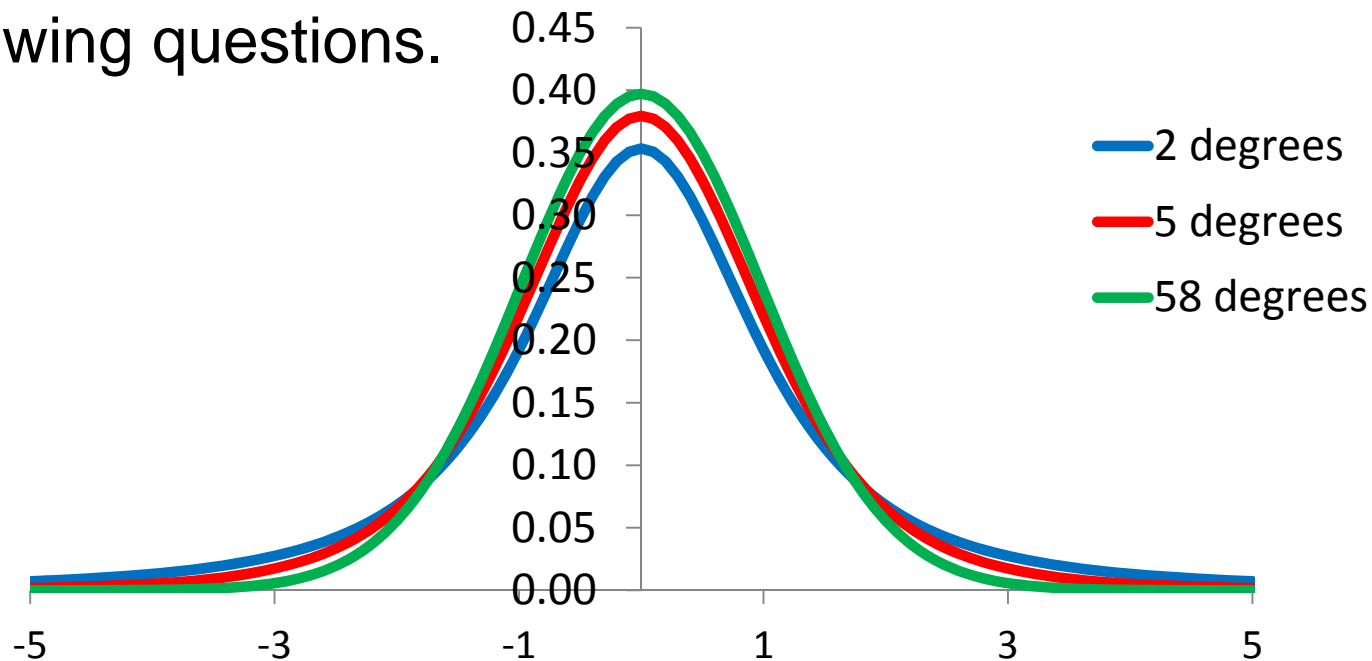
- ❑ Recall that the assumption that the population means are the same is called the **null hypothesis**.
- ❑ It is the hypothesis that we are checking.
- ❑ If the t-statistic is large enough, then we will reject the null hypothesis and conclude that populations have different means.
- ❑ However, if the t-statistic is not large enough to reject the null hypothesis, we *cannot* conclude that the populations have the same mean.
- ❑ In this case, all we can say is that the data do not support the conclusion that the populations have different means.

## How to compute the t-statistic

- ❑ If all of the following assumptions are met,
  - ❑ The populations are both normally distributed.
  - ❑ Both populations have the same variance.
  - ❑ Both populations have the same mean.
- ❑ then the t-statistic follows a student's t distribution with  $n_A + n_B - 2$  degrees of freedom.
- ❑ **NOTE: The concept of “degrees of freedom” is difficult to grasp, and will not be discussed in detail here.**
- ❑ **However, the number of degrees of freedom in a statistical test is related to sample size, and also determines the critical value of the test, which will be discussed a bit later.**

## How to compute the t-statistic

- ❑ Below is a figure showing several student's t distributions with varying degrees of freedom. Use this figure to answer the following questions.



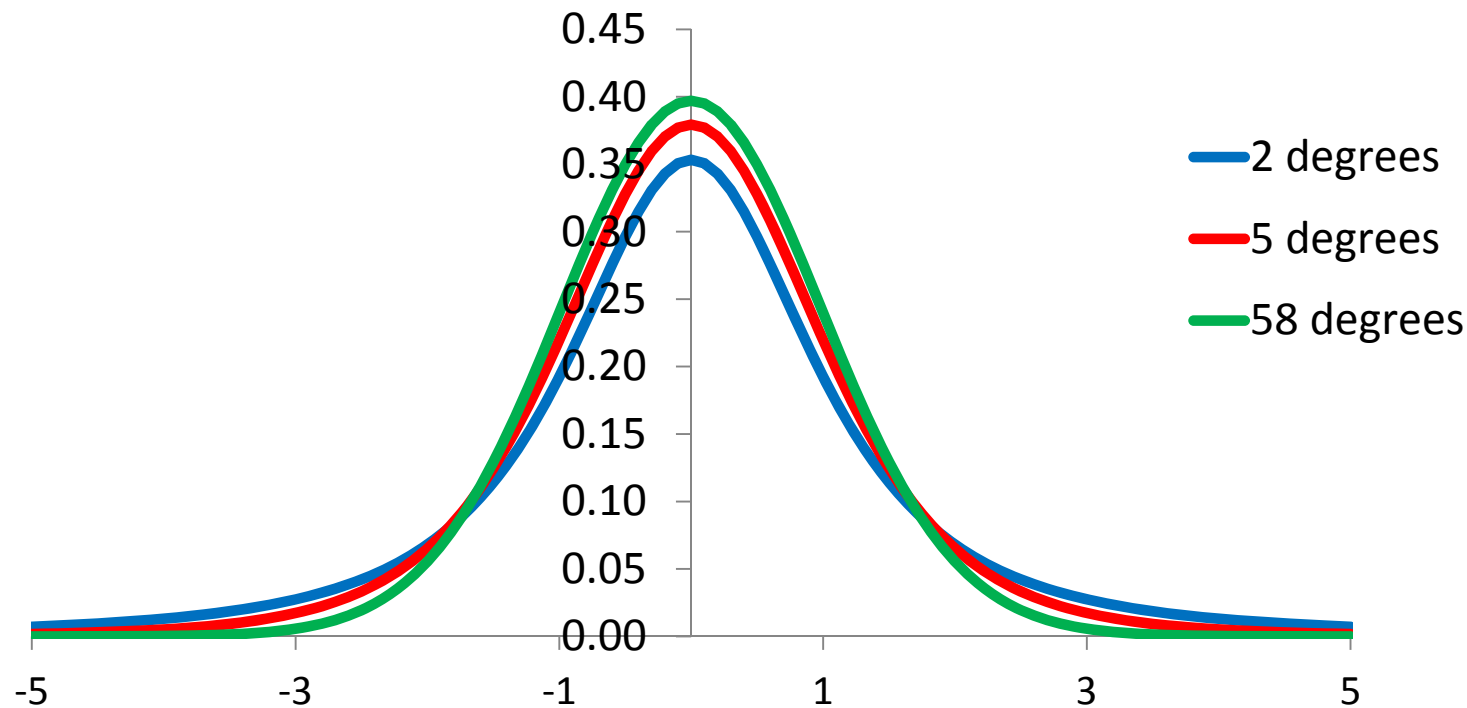
**Q27: How does the variance of the student's t distribution change with the degrees of freedom?**

**CLICK FOR THE ANSWER!**

**The variance of the student's t distribution decreases as the degrees of freedom increases.**

## How to compute the t-statistic

**Q28: If a t-statistic has a student's t-distribution with 58 degrees of freedom, how does the probability its absolute value is greater than 3 compare to the probability that its absolute value is less than 3?**

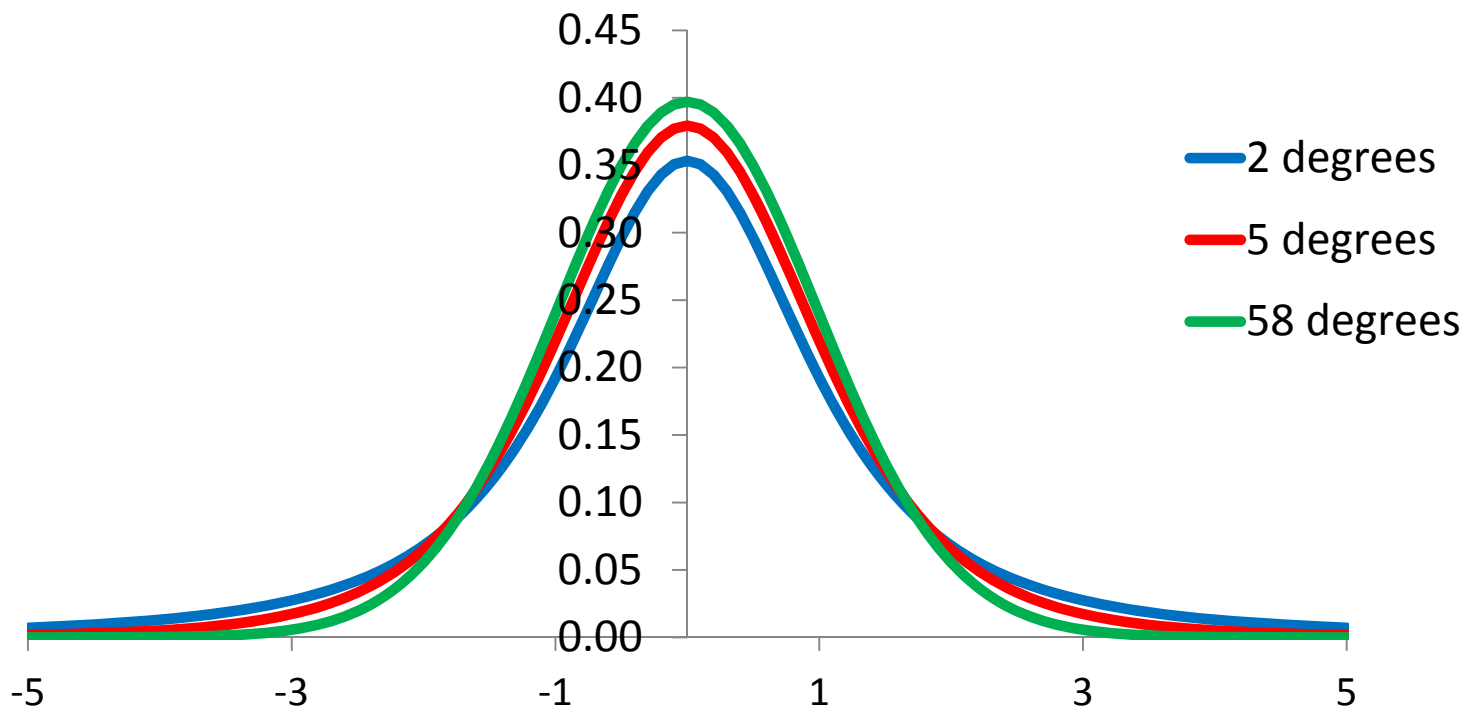


**CLICK FOR THE ANSWER!**

**The probability its magnitude is greater than 3 is less than the probability that its magnitude is less than 3.**

## How to compute the t-statistic

**Q29: As the sample size increases, what happens to the degrees of freedom? Remember, the number of degrees of freedom is equal to  $(n_A + n_B - 2)$**

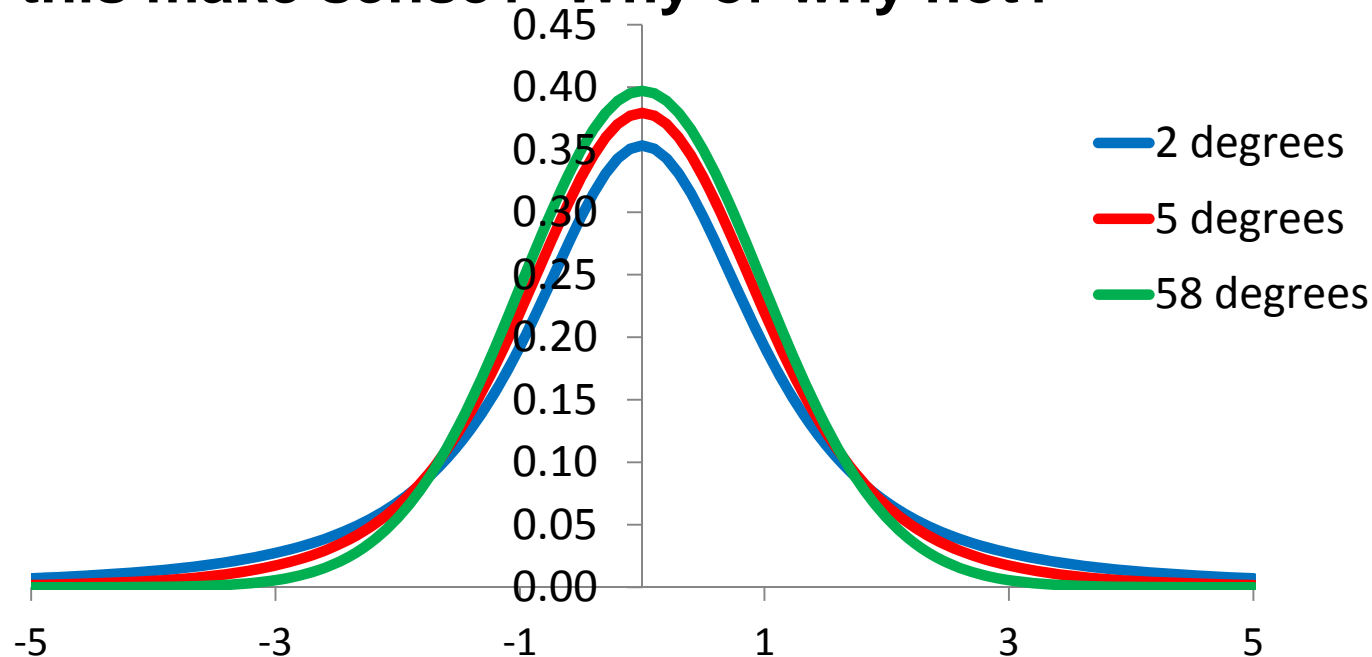


**CLICK FOR THE ANSWER!**

**As the sample size increases the degrees of freedom increases.**

## How to compute the t-statistic

**Q30: How does the probability that the absolute value of the t-statistic is bigger than 3 change as the sample size gets bigger? Does this make sense? Why or why not?**



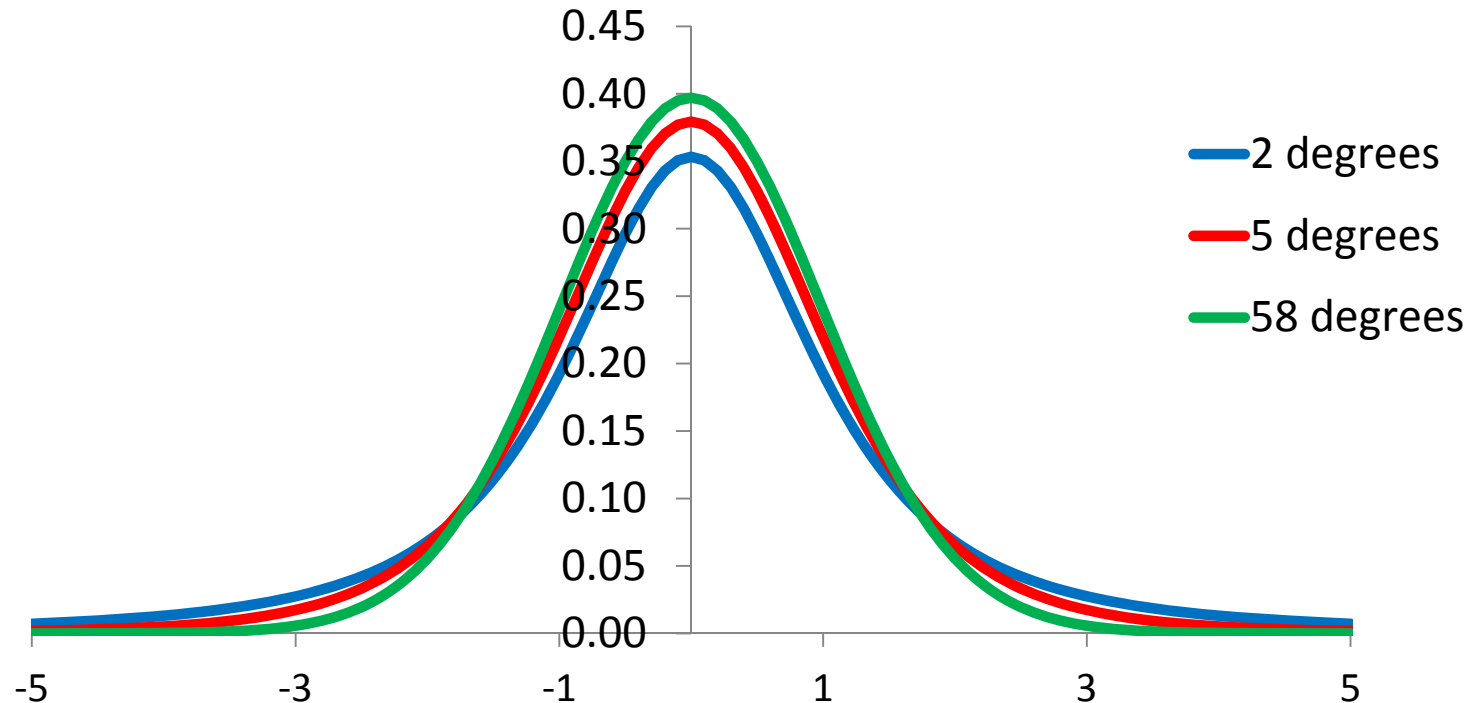
**CLICK FOR THE ANSWER!**

The probability that the t-statistic's magnitude is  $>$  than 3 decreases with increasing sample size. As the sample size increases the sample means approach the population means. Since we assume that the population means are the same this forces the difference of the sample means, and therefore the t-statistic, to be closer to zero.



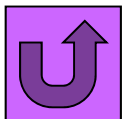
## How to compute the t-statistic

**Q31: Why do we reject the null hypothesis if the absolute value of the t-statistic is greater than or equal to  $x_c$ ?**



**CLICK FOR THE ANSWER!**

**We reject the null hypothesis if the t-statistic is greater than or equal to  $x_c$  because it is highly improbable that the t-statistic is this large if the null hypothesis is true.**

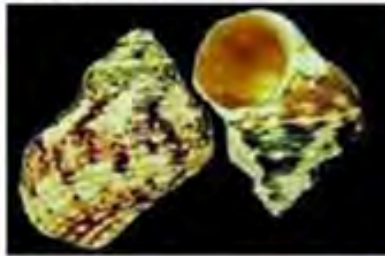


## Exercise 4: Simple Shell Match

- ☐ **In this exercise, you will use the shells** from containers C (red dot) and D (blue dot).
- ☐ The object of this game is to see if you can match each of the shells in these containers to pictures of various types of shells.
- ☐ To go to the pictures of possible shells in Container C:
- ☐ To go to the pictures of possible shells in Container D:

# Shells from Container C

Moon snail (family Naticidae) *Turbo* snail



Calico scallop



Pear whelk



Spindle (*Fusinus* sp.)



Rose cockle



Oyster



Flat scallop



Orange scallop



Nucleus scallop



Green limpet



Star limpet



Florida whelk

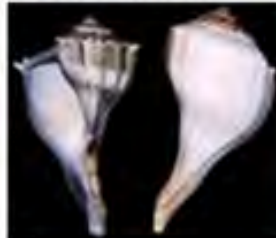


Fig whelk



Jingle clam



Turkey wing clam Auger shells



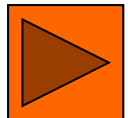
*Turitella* sp.



*Murex indiva*



*Nassarius* sp.





# Shells from Container C

White *Natica* sp.



King's Crown  
(many morphs)



Yellow land snail



Fig whelk



*Ecphora* (fossil)



Cebu Beauty



*Oliva gibbosa*



*Nassarius* sp.



Lined *Nerita* sp.



Lettered olive



*Strombus vittatus*



*Turritella* sp.



Candy cane tree snail



Horse conch



Money cowrie



Lace Murex



Sundials  
(family Architectonidae)



Spindle (*Fusinus* sp.)



*Babylonia* sp.



Moon snail  
(family Naticidae)



Apple Murex



Green Turbo



*Murex indiva*



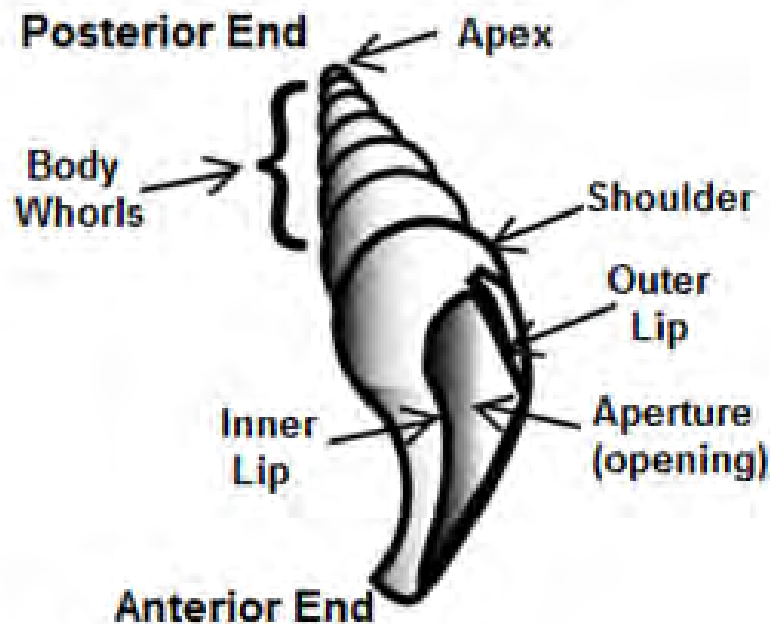
## Exercise 5: Making Sense of Variation: The Matching Game

- ☐ Mollusk shells come in an amazing variety of shapes, patterns and colors.
- ☐ There are about 100,000 species of mollusks, and many of these species have their own special shell.
- ☐ Although every shell is unique, individual shells may have some characteristics in common.
- ☐ We can sort shells by the characteristics they share, just as we sort the dishes in our kitchens. This exercise and the next demonstrate how biologists group organisms based on the characteristics they share.
- ☐ Check to see that each shell in Container C has a red dot on it. There should be a total of 30 shells in this container.
- ☐ Become familiar with the parts of a shell and the various shell types, textures, projections, and color patterns by studying Figures 1 & 2 on the next slides.

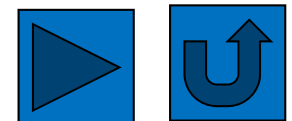
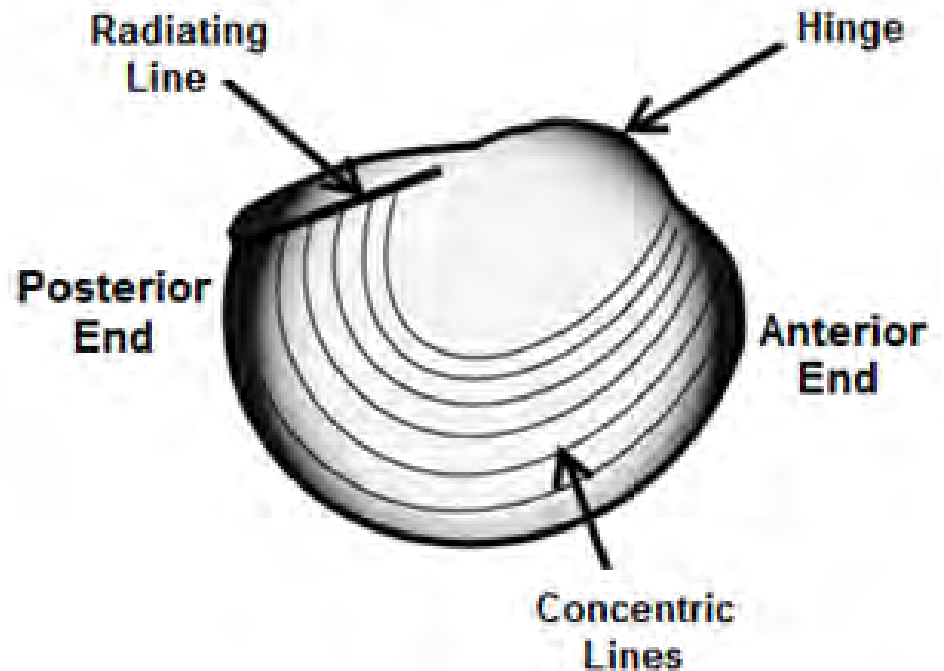
## Exercise 5: Making Sense of Variation: The Matching Game

**Figure 1: Parts of a gastropod (snail) shell and bivalve (clam) shell.**

### Gastropod Shell



### Bivalve Shell





# Exercise 5: Making Sense of Variation: The Matching Game

Figure 2. Example shell characteristics that can be used to sort shells.

## SPIRAL SHAPES

compressed



extended



## TEXTURES

smooth



horizontal ribs



vertical ribs



bumps



beads



grooves



## PATTERNS/MARKINGS

stripes



blotches



spots

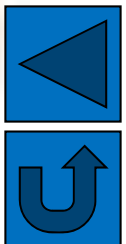


## PROJECTIONS

spines



teeth



## Exercise 5: Making Sense of Variation: The Matching Game

- ☐ Choose a shell from container C and examine it carefully.
- ☐ Now talk with the other students in your class and examine their shells in order to find those shells that most closely resemble your own shell.
- ☐ Form a group with the students whose shells most closely resemble your own.
- ☐ Once you have formed a group, devise a group name and write it on two sheets of paper.
- ☐ Identify the key characteristics that all of the shells in your group share, and record them on both sheets of paper.
- ☐ Find the black number on each shell in your group, and record these numbers on *one* of the sheets of paper.
- ☐ Give your shells to your teacher along with the sheet of paper that lists the shell characteristics but *does not* show the shell numbers.

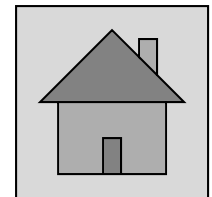


## Exercise 5: Making Sense of Variation: The Matching Game

- ❑ After all groups have turned in their shells and papers, the teacher will give each group a list of descriptive characteristics that was made by a different group.
- ❑ Now the teacher will spread the shells out on a long table.
- ❑ Collect all of the shells that have the characteristics from the list that the teacher gave your group.
- ❑ Record the shells' numbers on the sheet of paper that the teacher gave your group.
- ❑ Once all of the groups have finished, one at a time, each group should announce the group name from the top of the sheet of paper that the teacher gave them and then read the list of traits aloud while holding up the matching shells for the class to see. Also they should read the numbers on the shells so that the group that originally compiled the list can compare these numbers to the numbers on their own list.

## Exercise 5: Making Sense of Variation: The Matching Game

- ☐ As a class discuss how successful each group was at finding and collecting another group's shells. If a group was unable to collect all the correct shells, discuss what characteristics could be added to the list to make the task easier.
- ☐ Consult the answer sheet to Exercise 3 to find the name and type of each shell in container C.
- ☐ Please check to see that all red dot shells are placed back in Container C.



## Exercise 6: Finding Species

- ❑ In this exercise, you will learn about **hierarchy** and **classification**.
- ❑ When scientists classify organisms, they do more than just separate the organisms into groups of like organisms, they also reveal how the organisms are related, or how similar they are.
- ❑ Suppose, for example that you wanted to classify the officials in our federal government. You might start by assigning government officials to the following groups.

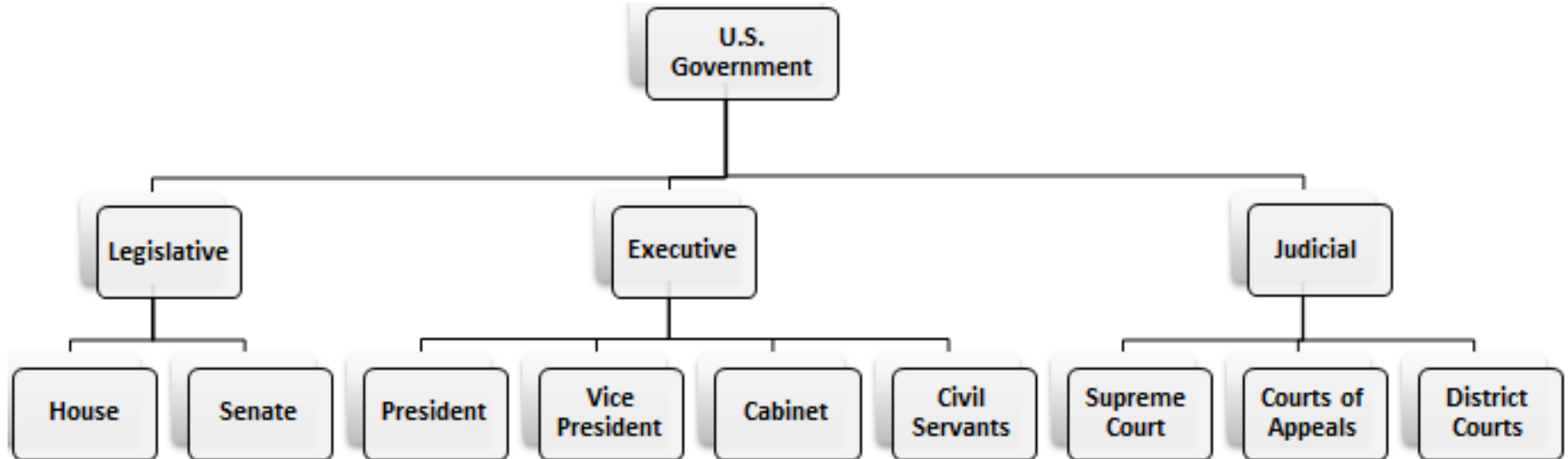
|               |                 |                          |
|---------------|-----------------|--------------------------|
| President     | Civil Servants  | Courts of Appeals        |
| Cabinet       | Senate          | Vice President           |
| Supreme Court | District Courts | House of Representatives |

## Exercise 6: Finding Species

|               |                 |                          |
|---------------|-----------------|--------------------------|
| President     | Civil Servants  | Courts of Appeals        |
| Cabinet       | Senate          | Vice President           |
| Supreme Court | District Courts | House of Representatives |

- ❑ However, the grouping above doesn't tell us anything about how the government functions, or how these groups are related.
- ❑ In order to see how these groups of government officials are related, we need to create a tree diagram which shows the **classification hierarchy**, that is, the criteria by which these groups of officials are classified, and the order in which these criteria are considered.
- ❑ On the following slide, you will see an example of such a diagram.

## Exercise 6: Finding Species



- ❑ The diagram above shows that the government is broken into three separate branches, which are responsible for the three basic tasks of governing.
- ❑ Then, each branch of government is broken into groups of officials that are charged with specific duties.
- ❑ That is, government officials are classified first by the branch of government that they belong to, and then by their specific title.

## Exercise 6: Finding Species

- ☐ As a second example, we can classify the students in your class by their birth place. In this example, the criteria of classification would be birth country, birth state or province, and then birth city, in that order.
- ☐ Create a tree diagram to show how the students in your class are classified based on place of birth.
- ☐ Examine the objects below and create a hierarchy by which to classify them.



- ☐ Draw a tree diagram to show how the objects are related through your classification hierarchy.
- ☐ There are many possible responses.
- ☐ Talk with other students in your class to see how they classified the objects.

## Exercise 6: Finding Species

- ☐ The classification hierarchies that we have examined so far are small compared to the hierarchy by which scientists classify life.
- ☐ The first criteria by which scientists classify life is called the kingdom.
- ☐ One kingdom is the kingdom Animalia (the animals). This kingdom consists of multicellular organisms that obtain their food by eating other organisms.
- ☐ The kingdoms are then divided into phyla.
- ☐ The animal kingdom is divided into approximately 30 phyla, which share similar body plans.
- ☐ One phylum is the phylum Mollusca (mollusks).
- ☐ Mollusks are characterized by the presence of a body cavity that contains organs, a mantle cavity that provides gas exchange, and a protective shell.

## Exercise 6: Finding Species

- ☐ Each phylum is divided into classes.
- ☐ There are five classes in the kingdom Mollusca.
- ☐ The two classes of mollusks used in this exercise are the Gastropoda (snails and their relatives) and the Bivalvia (clams and their relatives).
- ☐ There are four additional levels of classification below the class level in this hierarchy: order, family, genus and species.
- ☐ In this exercise, your goal is to play the role of a **taxonomists** (scientists who focus on classifying living organisms).
- ☐ In this exercise, you will classify the mollusk shells in Container C and then those in Container D by successively partitioning them into two groups until each group is composed only of shells that are very similar in appearance.
- ☐ When you are finished, each group of shells that result from your classification hierarchy will represent a species, at least as you define the term.

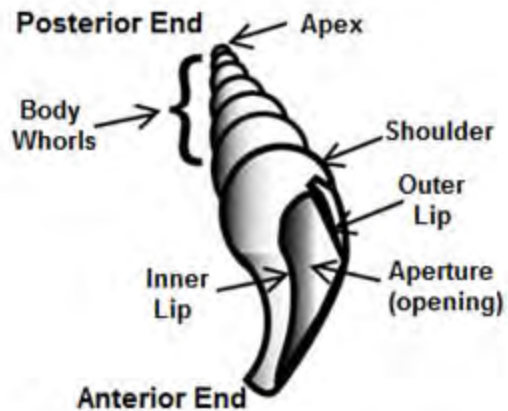


## Exercise 6: Finding Species

- ☐ Spread the shells from container C out onto a long table. All of these shells should have a red dot. (Remove any shells that have a blue dot and return them to container D).
- ☐ Consult the diagrams on the next slide to see parts and characteristics of shells that you may want to use in your classification.
- ☐ Can you think of any other criteria by which to classify these shells?

# Exercise 6: Finding Species

## Gastropod Shell



## SPIRAL SHAPES

compressed



extended



## TEXTURES

smooth



horizontal ribs



vertical ribs



bumps



beads



grooves



## PATTERNS/MARKINGS

stripes



blotches



spots



## PROJECTIONS

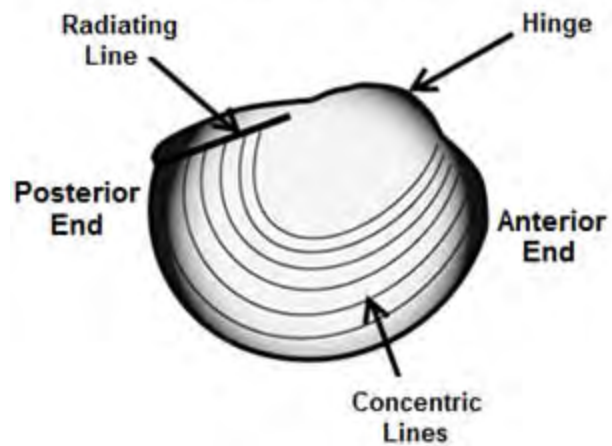
spines



teeth

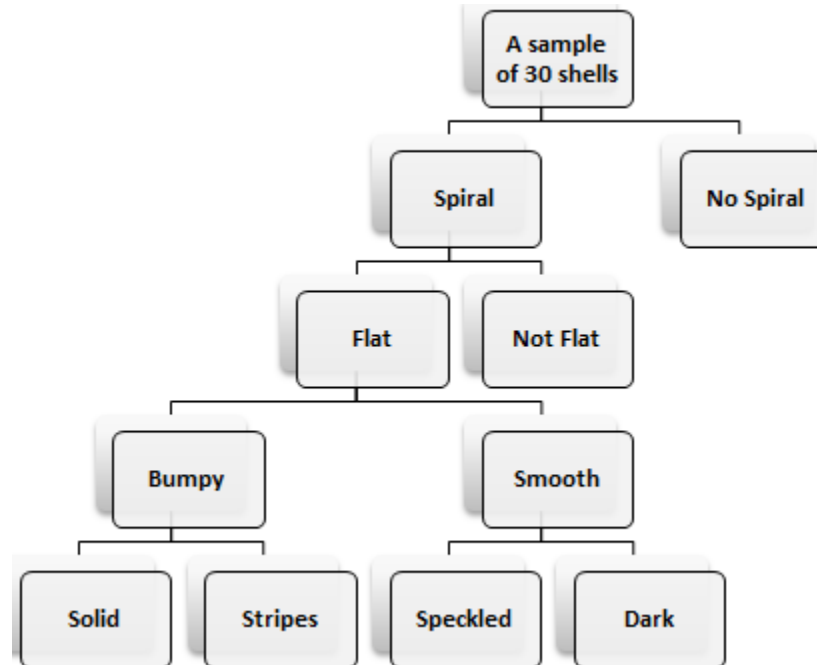


## Bivalve Shell





## Exercise 6: Finding Species

- ❑ Pick a characteristic by which to separate the shells into 2 groups.
- ❑ Write the two variants of the characteristic on the board. Your goal is to make a tree diagram like the one below:



- ❑ Continue to choose criteria by which to divide your groups, and update your diagram accordingly until each group consists only of shells that are very similar in appearance. As shown in the figure, you may finish partitioning one group of shells before the other.

## Exercise 6: Finding Species

- ☐ It will be helpful if you keep track of the numbers of each shell that you place into each group at each split in your hierarchical diagram, as this will facilitate quick location/identification of shells when discussing this exercise in class.
- ☐ Label each final group on your diagram with the numbers of the shells that belong to that group.
- ☐ Consult the answer sheet on the inside of the lid of Container C to see that each of your groups consists only of shells from the same species.
- ☐ Repeat this exercise, using the shells in Container D.
- ☐ To learn more about species concepts: 
- ☐ To go back to the homepage: 

## Species concepts & “lumpers” vs “splitters”

- ❑ In the previous exercise, you played the role of taxonomists, deciding where to draw the line between *species* represented by the samples of shells in your containers.
- ❑ Many of you may have arrived at different decisions on which shells constituted species in the previous exercise.
- ❑ This should illustrate to you a fairly important point: taxonomy is a human construct.
- ❑ Of course, some organisms are more closely related to one another than others, but how scientists break them into various taxonomic groups is a way that humans have devised to help organize closely related organisms together in a way that makes sense.
- ❑ Defining larger groups (orders, families, classes, phyla/divisions, kingdoms/domains) of organisms that share a common ancestry and traits is a work in progress, and often used as an example of how science is self-correcting, yet what defines a **species** is also a major topic of debate.

## Species concepts & “lumpers” vs “splitters”

- ❑ The big question for many biologists is “where **do** we draw the line at what constitutes a species?”
- ❑ There are tons of different concepts that have been used in both historical and modern contexts on what defines a “species”.
- ❑ Taxonomists use all sorts of criteria on dividing species (morphology, ecology, genetics, ability to mate and produce viable offspring etc.).
- ❑ It often seems, to many biologists, that there are nearly as many different species concepts as there are types of living organisms!
- ❑ Ask any two biologists their definition of a species, and you may get very different answers.
- ❑ On the following slide, you will learn about several different **species concepts**, as well as different approaches used by taxonomists.

## Species concepts & “lumpers” vs “splitters”

- ❑ Most (though not all) biologists define species using the **biological species** concept.
- ❑ The biological species concept is one of the first more formal definitions of species, and defines a species as consisting of “**a group of interbreeding populations that are reproductively isolated from other such groups**” (Mayr, 1942).
- ❑ This definition is one of the more commonly used ones for a species, though again, many other biologists define species in different ways.
- ❑ However, there are several other major species concepts that are used by other scientists to define a species. These concepts differ in various ways, but may sometimes agree (though they may often disagree) on when to call two organisms different species.
- ❑ A little later, you will learn more about some other major species concepts on your own or in teams.

## Species concepts & “lumpers” vs “splitters”

- ❑ How taxonomists classify organisms into species usually falls somewhere between two opposite ends of a spectrum of “**lumpers**” and “**splitters**”.
- ❑ A “**lumper**” would be a taxonomist that groups (lumps) together lots of different organisms in the same species on the basis of several broad similarities that they view as being important characteristics that defines the species.
- ❑ “Lumpers” generally view species as biological units that may display a **very broad range of inter-individual variation**.



## Species concepts & “lumpers” vs “splitters”

- ❑ On the other hand, a taxonomist who separates organisms into separate species on the basis of lots and lots of smaller details would be known as a “**splitter**”.
- ❑ Splitters generally take the following views:
  - ❑ Species may **display some important degree of inter-individual variation**.
  - ❑ However, species are biological entities that **display a lot of** important (though often miniscule) **highly-conserved traits**.
  - ❑ Substantial variation beyond those highly-conserved traits is worthy of giving other organisms their own formal species names.

## Species concepts & “lumpers” vs “splitters”

- ❑ Lumping and splitting can both be viewed as having value in different ways, but both “schools of thought” in taxonomy have drawn some criticism.
- ❑ A quote from George Simpson, a famous paleontologist (a scientist that studies fossils) once provided the following tongue-in-cheek definitions of both:

*"Splitters see very small, highly differentiated units – their critics say that if they can tell two animals apart, they place them in different genera ... and if they cannot tell them apart, they place them in different species. ... Lumpers, on the other hand, see only large units – their critics say that if a carnivore is neither a dog nor a bear, they call it a cat."*

## Species concepts & “lumpers” vs “splitters”

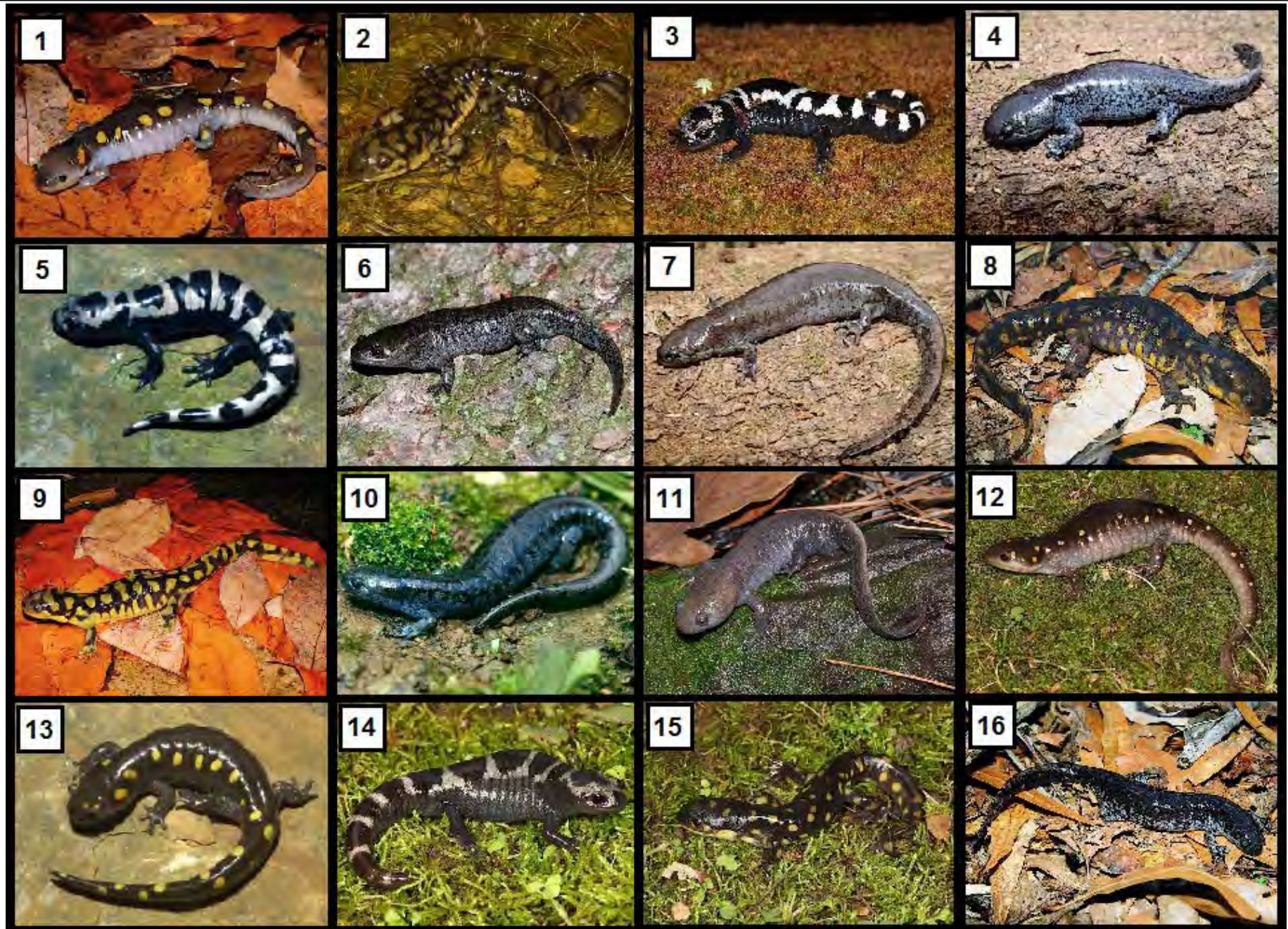
- ❑ On the following slides, you will play the role of taxonomists, using images of several groups of organisms, many of which you might even see here in Tennessee!
- ❑ You should work through these groups of organisms in order:
  - ❑ First, you will look at salamanders in the genus *Ambystoma*.
  - ❑ Next, you will examine lady beetles (ladybugs) in the family Coccinellidae.
  - ❑ Finally, you will examine spiders in the genus *Agelenopsis*.  
**NOTE:** Since spiders often exhibit **sexual dimorphism**, the images of the spiders in this exercise are females only.
- ❑ **ALSO NOTE:** The slides with organism identities are found after each of the picture slides, so don't click past a set of images until all students have decided how many species they think are present in that set of images!

## Species concepts & “lumpers” vs “splitters”

- ☐ For this exercise, you should work in groups of 3-4.
- ☐ For each group of organisms, examine the numbered pictures of individuals in that group.
- ☐ Discuss with your teammates the visible characteristics of the individuals, and see if you can come to a consensus decision on how many species are represented by that group of images.
- ☐ You may find it helpful to draw hierarchical tree diagrams as you did in the previous exercise to help you keep track of traits that you used to separate the organisms into species.
- ☐ After the entire class is finished sorting a particular group into species, get your teacher, or a scribe from your team, to write on the board how many species you think is in that group.



# Species concepts & “lumpers” vs “splitters”





## Species concepts & “lumpers” vs “splitters”

### Key to salamander species

**Spotted Salamander (*Ambystoma maculatum*): 1, 12, & 13**

**Marbled Salamander (*Ambystoma opacum*): 3, 5, & 14**

**Mole Salamander (*Ambystoma talpoideum*): 4, 6, & 11**

**Smallmouth Salamander (*Ambystoma texanum*): 7, 10, & 16**

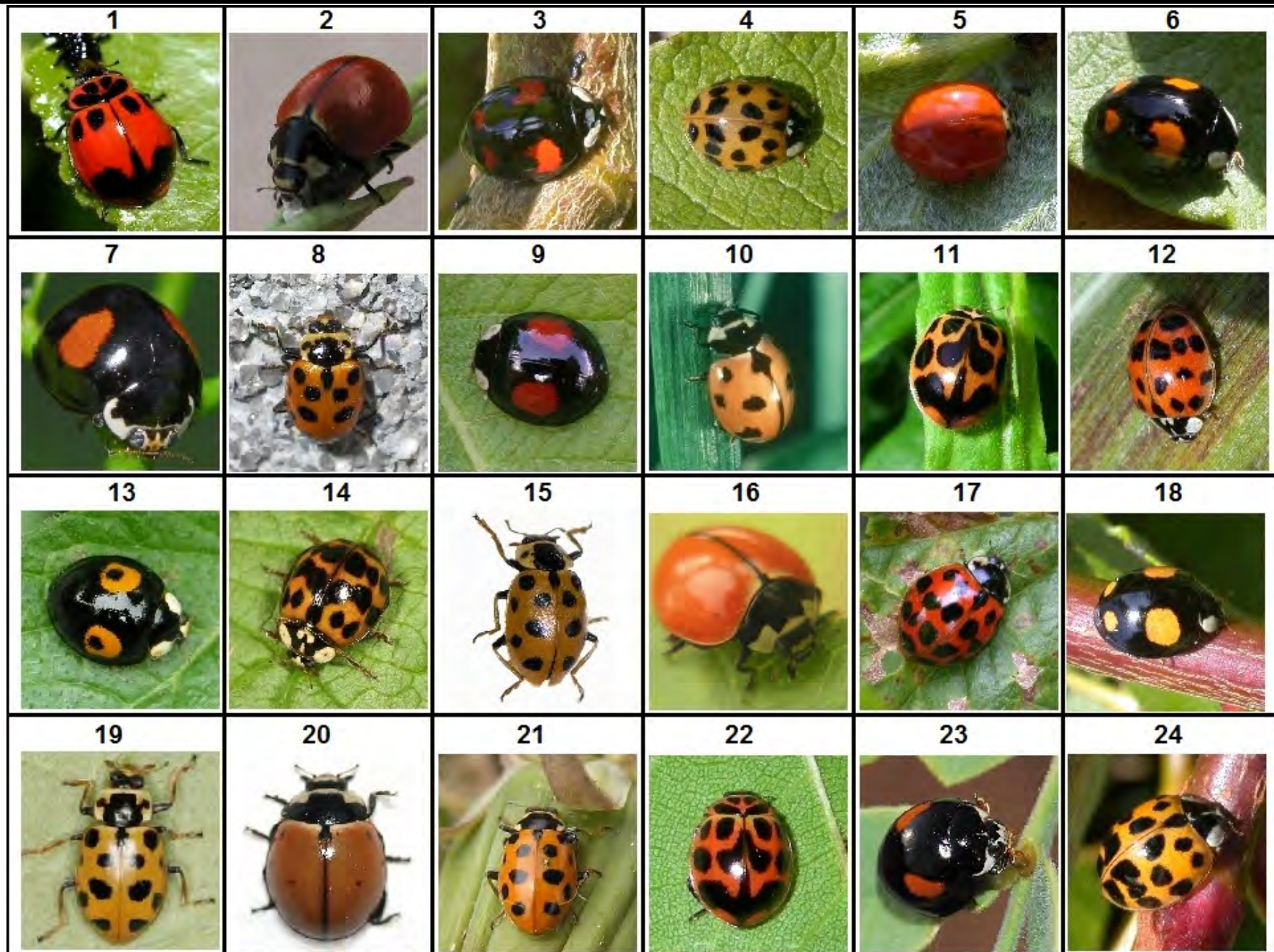
**Eastern Tiger Salamander (*Ambystoma t. tigrinum*): 2, 8, 9, & 15**

☐ Go to the next slide for additional details on identifying these species!

## Species concepts & “lumpers” vs “splitters”

- ☐ This set should have been fairly easy, but a few of the species may have tricked you a little due to some variation:
- ☐ The Spotted Salamander & Eastern Tiger Salamander have spots.
- ☐ The coloration of the spots on the Spotted Salamander may be similar in coloration to the spots on the Eastern Tiger Salamander, but the Spotted Salamander's spots are nearly perfectly round, and not as numerous as those in the Eastern Tiger Salamander.
- ☐ The Mole Salamander and the Smallmouth Salamander have similar coloration, but the Mole Salamander's head is much larger in proportion to the rest of its body.
- ☐ Also note the strong keel (ridge) on the dorsal (upper) surface of the Mole Salamander's tail.
- ☐ The Marbled Salamander displays some variation, with the light coloration on its back ranging from dark grey to almost white.
- ☐ However, its overall pattern and large body size make it practically unmistakable for any other salamander in the U.S.

# Species concepts & “lumpers” vs “splitters”





## Species concepts & “lumpers” vs “splitters”

### Key to Lady Beetle Species

**Nine-spotted Lady Beetle (*Coccinella novemnotata*):** 2, 10, 16, & 20

**Multicolored Asian Lady Beetle (*Harmonia axyridis*):** 3, 4, 5, 6, 9, 12, 13, 14, 17, 18, & 24

**Thirteen-spotted Lady Beetle (*Hippodamia tredecimpunctata*):** 8, 15, 19, & 21

**V-marked Lady Beetle (*Neoharmonia venusta venusta*):** 1, 11, & 22

**Ashy Gray Lady Beetle (*Olla v-nigrum*):** 7 & 23 (the ones in the exercise are the black and orange form of this species, which also comes in a gray, spotted form like the one pictured below:



## Species concepts & “lumpers” vs “splitters”

- ❑ More than likely, your decisions on how to group these lady beetles into species relied solely on the obvious variation in color, pattern, and possibly shape, which are the most commonly used means of identification of beetles within this family.
- ❑ However, other characteristics such as spines on the legs and feet, as well as grooves on the underside of the thorax, which you were not able to see, are also used to identify genera and species in this family.
- ❑ Almost half of the lady beetles in the images belong to the species *Harmonia axyridis*, an invasive species from Asia.

## Species concepts & “lumpers” vs “splitters”

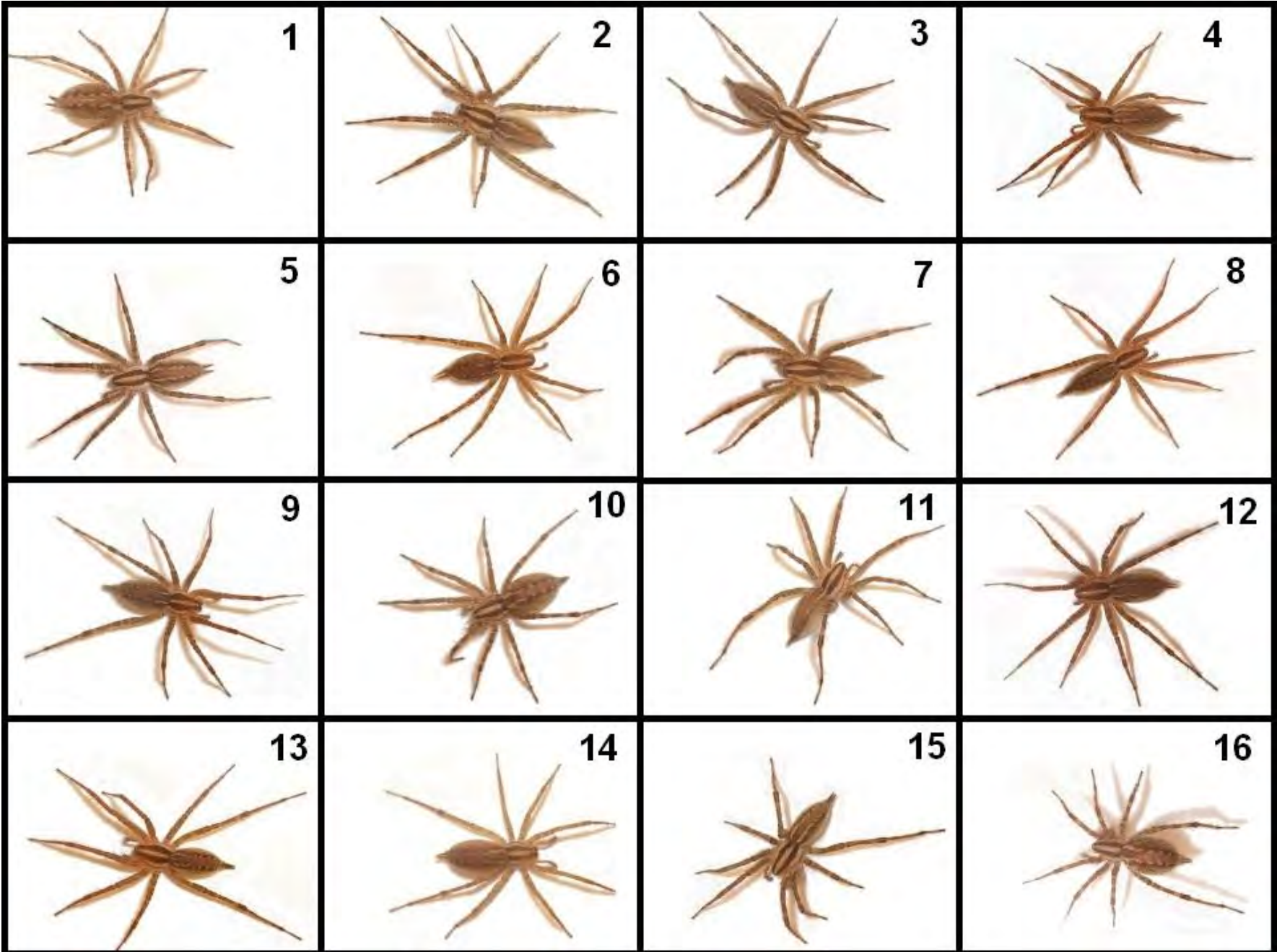
- ❑ *Harmonia axyridis* is highly variable, displaying an astounding amount of variation in color and pattern.
- ❑ However, it can often be distinguished by a black “M” shape on the pronotum (the area between the head and the wings), though this shape may be broken up, or obscured by a larger dark blotch.
- ❑ See the image below for an example of the variation observable within *H. axyridis*:



## Species concepts & “lumpers” vs “splitters”

- ❑ *Harmonia axyridis* was introduced to the U.S. in CA in 1916, again in CA in 1964 and 1965, in WA from 1978-1982, and throughout Canada and the Eastern U.S. from 1978-1981 as a means of biological control of aphids.
- ❑ However, this beetle spread throughout the U.S. and Canada rapidly, becoming very common throughout North America by 1994.
- ❑ This species has actually become a nuisance, often invading homes, where they seek shelter from the cold in the winter.
- ❑ It has also become problematic by outcompeting many native lady beetle species, such as the other ones pictured in this exercise.
- ❑ In fact, since the introduction of *H. axyridis*, *Coccinella novemnotata* (the Nine-spotted Lady Beetle), has almost disappeared entirely from the eastern U.S.

# Species concepts & “lumpers” vs “splitters”



## Species concepts & “lumpers” vs “splitters”

### Key to spider species

***Agelenopsis aleenae*: 3, 5, & 15**

***Agelenopsis aperta*: 1, 10, & 16**

***Agelenopsis emertoni*: 6, 9, 12**

***Agelenopsis pennsylvanica*: 4, 8, 13**

***Agelenopsis potteri*: 14**

***Agelenopsis spatula*: 2, 7, 11**

- ☐ Go to the next slides for more information about these spiders!

## Species concepts & “lumpers” vs “splitters”

- ❑ You may have noticed that most of the spiders in these images were very, very similar.
- ❑ However, taxonomists who specialize in arachnology (the study of spiders) classify members of the genus *Agelenopsis* into different species based on the shapes and characteristics of male and female reproductive organs, which are not readily visible in these images.
- ❑ Also, many of these species occur in geographic ranges (and habitats within ranges) that do not overlap, which many warrant as worthy of species status.
- ❑ These are basically the only means of distinguishing among some species in this genus.



## Species concepts & “lumpers” vs “splitters”

- ❑ Traditionally, many spider biologists viewed the shapes of male and female spider genitalia as a sort of “lock and key” model of species.
- ❑ In such a model, the shape of a male’s pedipalps determines and limits with which females he would be able to mate.
- ❑ This does appear to be the case in several species of *Agelenopsis* with overlapping ranges (males of a “species” only mate with females of the same species in those areas).
- ❑ However, genetic data from a few species suggests that some hybridization within “species groups” composed of several formally described species may occur (Ayoub, Riechert, & Small 2005).
- ❑ How do *Agelenopsis* spiders tell each other apart?
- ❑ It seems to be based on olfactory cues.
- ❑ In other words, females are thought to release a species-specific pheromone that attracts males of the same species and elicits courtship from them.



## Species concepts & “lumpers” vs “splitters”

- ❑ Now that you have examined each of these groups of organisms, answer the following questions via class discussion.
  - ❑ Did the teams differ in the number species they identified in the three groups? If so, which teams would be considered “lumpers,” which would be considered “splitters,” and which teams would fall somewhere in between?
  - ❑ What proportion of the teams could be classified as lumpers, as splitters, or as ‘tweeners’ (in between lumpers and splitters)?
- ❑ Now organize yourselves into three larger teams (lumpers, splitters, and 'tweeners') based on the number of "species" your smaller teams identified.
- ❑ Take a few minutes to discuss with your larger team, and then, as a class, your overall reasoning for the number of species that you identified (in other words, why you fell on a particular end, or the middle, of the lumpers/splitter spectrum).

## Species concepts & “lumpers” vs “splitters”

- ☐ We have already discussed the biological species concept.
- ☐ Now, take some time to do some research and find some definitions of the following species concepts:
  - ☐ **Typological species concept**
  - ☐ **Ecological species concept**
  - ☐ **Evolutionary species concept**
- ☐ See if you can find other popular species concepts & their definitions.
- ☐ Now try to answer the following questions:
  - ☐ Which species concept do you think is the closest to the one you used in dividing up the images in each group into species?
  - ☐ Which species concept seems most sensible to you, & why?
  - ☐ Why is the notion of how one defines a species important?
- ☐ Go to the next slide for further information!

## Species concepts & “lumpers” vs “splitters”

- ❑ Below are definitions of the three major species concepts mentioned in this exercise.
- ❑ **Typological species concept** – A species is a certain “type” of organism that looks different than another.
- ❑ **Ecological species concept** – A species is a set of organisms exploiting (or adapted to) a single niche (Ridley 1993).
- ❑ **Evolutionary species concept** – A species is a single lineage of populations which has its own unique evolutionary history and tendencies (Wiley, 1981).

## Species concepts & “lumpers” vs “splitters”

- ☐ In determining which individuals constituted separate species in this exercise, you undoubtedly relied on the typological species concept.
- ☐ This is because you had no prior information on which of the species represented are capable of interbreeding, nor on the populations from which they came.
- ☐ The species identifications listed in the keys for this exercise are agreed on by most specialists who work with those particular organisms.
- ☐ However, further changes in taxonomy are always possible, as more data about those organisms are gathered!

## Species concepts & “lumpers” vs “splitters”

- ❑ Why are species concepts important, anyway?
- ❑ One reason (of many) is that how we define a species has a big impact on when and how conservation efforts are implemented!
- ❑ The U.S. Endangered Species Act defines a “species” as “any ***subspecies*** of fish or wildlife or plants, and ***any distinct population segment*** of any species of vertebrate fish or wildlife which interbreeds when mature.”

## Species concepts & “lumpers” vs “splitters”

- ❑ This means that specific populations of vertebrates in a particular area, such as grizzly bears, salmon, wolves, etc. can be classified as endangered, even if they are not threatened in other parts of their range, even if they are not described as separate species/subspecies.
- ❑ However, significant populations of other organisms (invertebrates, plants, etc.) can only be protected in parts of their range where they may be threatened only if they are recognized and ***formally described*** as a distinct species or subspecies!
- ❑ Thus, you can see why species concepts are important to lots of biologists, and why they are a hot topic!

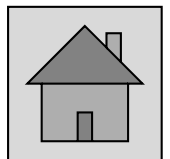


## Exercise 7: Mystery Shell

- ☐ Examine the “mystery shell” in Container E.
- ☐ See if you can figure out what kind of shell it is.
- ☐ Go to the next slide to see if you were right!

## Exercise 7: Mystery Shell

- ☐ The mystery shell is actually the **operculum** of a snail.
- ☐ The operculum is a shell door, which many (but not all) snails have.
- ☐ With this door, the snail is able to close its shell to survive periods of drought and to gain protection against predators.
- ☐ Snails that live along the seashore are often exposed to air when the tide goes out, and there are many animals that feed on snails, especially birds.
- ☐ In those situations, an operculum is a valuable adaptation!



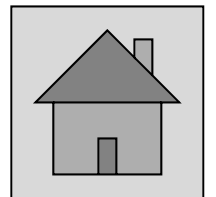


## Exercise 8: Mechanisms Underlying Variation

- ☐ So far in our exploration of variation, we have seen that individuals vary, and we have learned how to measure variation within a population.
- ☐ We have also seen that populations vary, and learned to measure the significance of inter-population variation.
- ☐ We have also learned that individuals can be classified according to their differences via a classification hierarchy.
- ☐ This exercise introduces the mechanisms that underlie trait variation.
- ☐ We will use leaves and flowers as examples.
- ☐ You have also been presented with an additional sample of gastropod shells.
- ☐ You will use these for an exercise that allows you to explore the concept of variation among species in the context of adaptations.

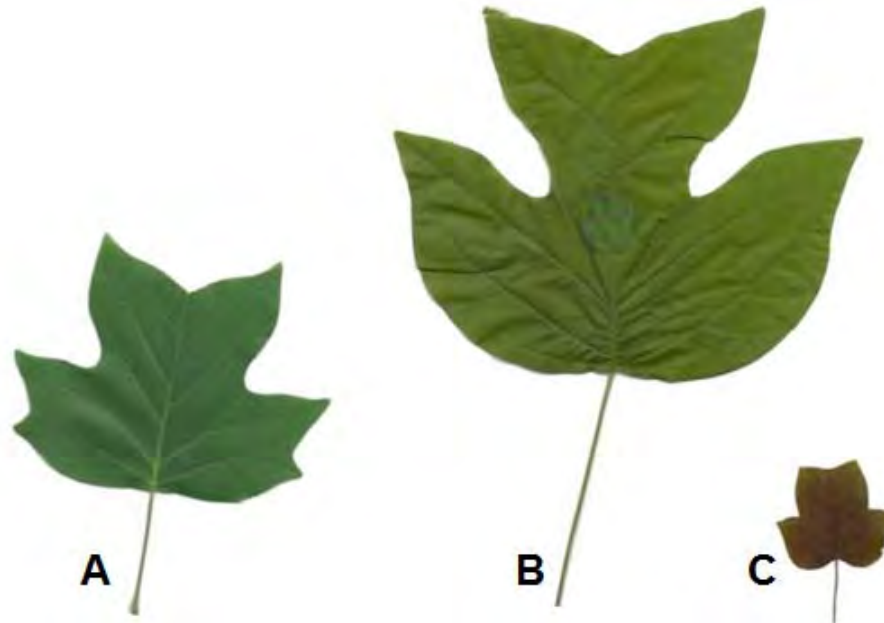
## Exercise 8: Mechanisms Underlying Variation

- ❑ Click **HERE** to go to Exercise 8a:  
Variation in Leaves & Flowers.
- ❑ Click **HERE** to go to Exercise 8b:  
Variation in Snail Shells.
- ❑ Click **HERE** to go to Exercise 8b.2, which  
is an open-ended exploration of adaptive  
variation in snail shells.



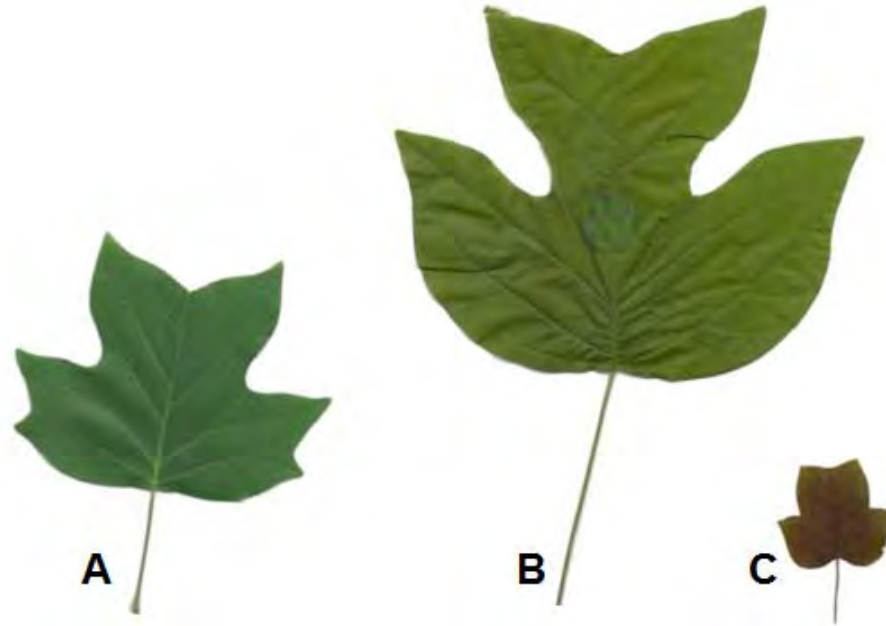
## Exercise 8a: Variation in Leaves & Flowers

- ☐ Examine the leaves below. These leaves were collected from the same tree. In fact, they all came from the same branch.
- ☐ Note that individual leaves differ in size.
- ☐ Within a single species, differences in size are frequently associated with differences in age or developmental stage.
- ☐ As a leaf unfolds from its leaf bud, it gains room to grow larger.
- ☐ All it needs is time and nourishment in order to grow to the size of a typical mature leaf.



## Exercise 8a: Variation in Leaves & Flowers

**Q1.** Can you rank the leaves below from youngest to most mature? Which species of tree did these leaves come from?

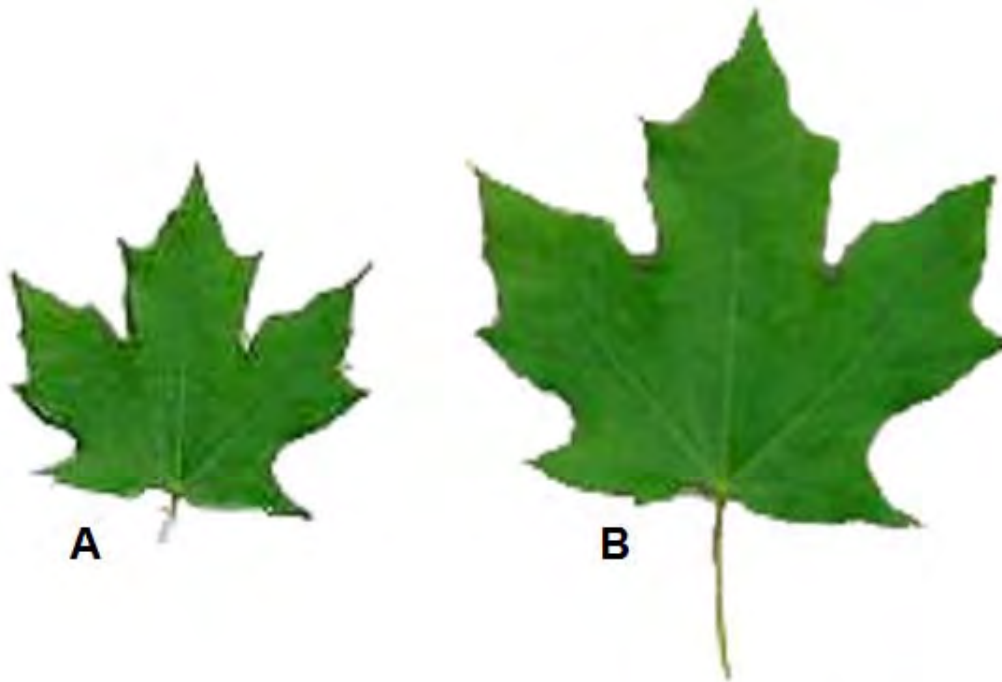


**CLICK FOR THE ANSWER!**

When ranked from youngest to most mature (with younger leaves being smaller than more mature leaves), the order is C, A, B. These leaves came from a Tulip Poplar (*Liriodendron tulipifera*).

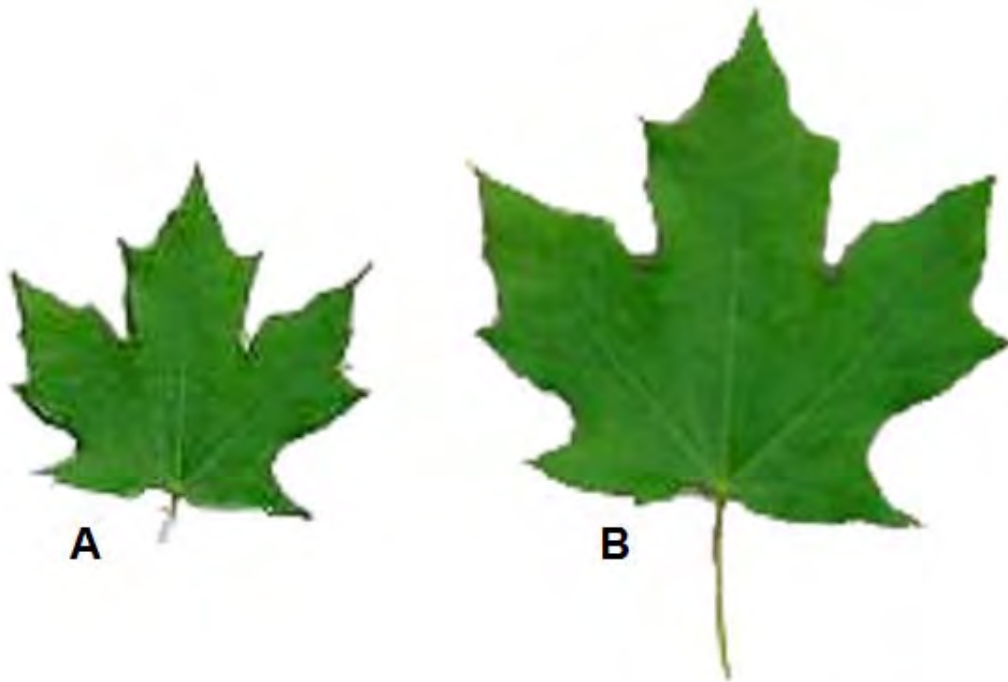
## Exercise 8a: Variation in Leaves & Flowers

- ☐ Now examine the two leaves below.
- ☐ Unlike the previous leaves, these leaves are both mature, and yet they differ markedly in size.
- ☐ As you can see, leaf B has a much greater surface area than leaf A.
- ☐ However, leaf A is actually thicker than leaf B.
- ☐ These leaves came from different parts of the same tree.



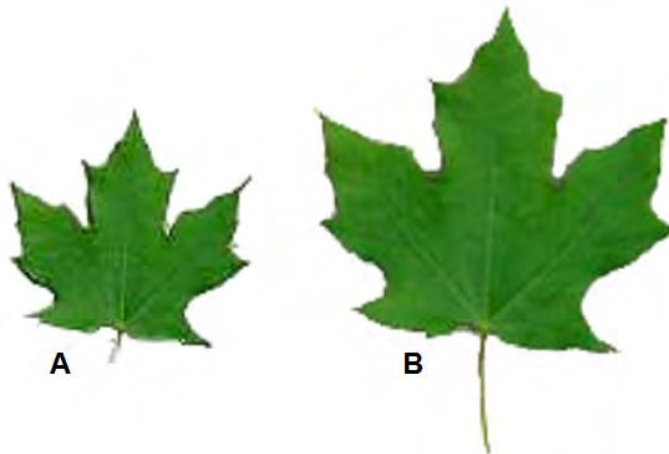
## Exercise 8a: Variation in Leaves & Flowers

- ☐ One of the leaves is a **sun leaf** which was collected from a branch near the top of the tree.
- ☐ The other leaf is a **shade leaf** which was collected from one of the lower branches.
- ☐ The size of these leaves was influenced by their environment and the special needs of trees.



## Exercise 8a: Variation in Leaves & Flowers

- ☐ Unlike animals that must consume food to obtain energy, trees obtain energy by making their own food when sunlight hits their leaves.
- ☐ In order to convert sunlight to usable chemical energy, plants need water, and lots of it.
- ☐ For example, it is estimated that the typical oak tree (not the type of tree whose leaves are pictured below) needs about 50 gallons of water a day.
- ☐ Therefore, lack of water and light can severely limit the amount of sugars (food) that a tree leaf can produce.



## Exercise 8a: Variation in Leaves & Flowers

- ☐ Because the top of the tree receives more intense sunlight than the bottom of the tree, leaves at the top of the tree are able to produce more food per unit surface area than leaves at the bottom of the tree.
- ☐ However, leaves at the top of the tree are also subject to greater water loss per unit surface area, also because they are exposed to more sun and wind.

**Q2.** Why does the top of the tree typically receive more sun than the bottom of the tree?

**CLICK FOR THE ANSWER!**

**The top of the tree typically receives more sun than the bottom of the tree because throughout most of the day the bottom of the tree is shaded by the top of the tree.**



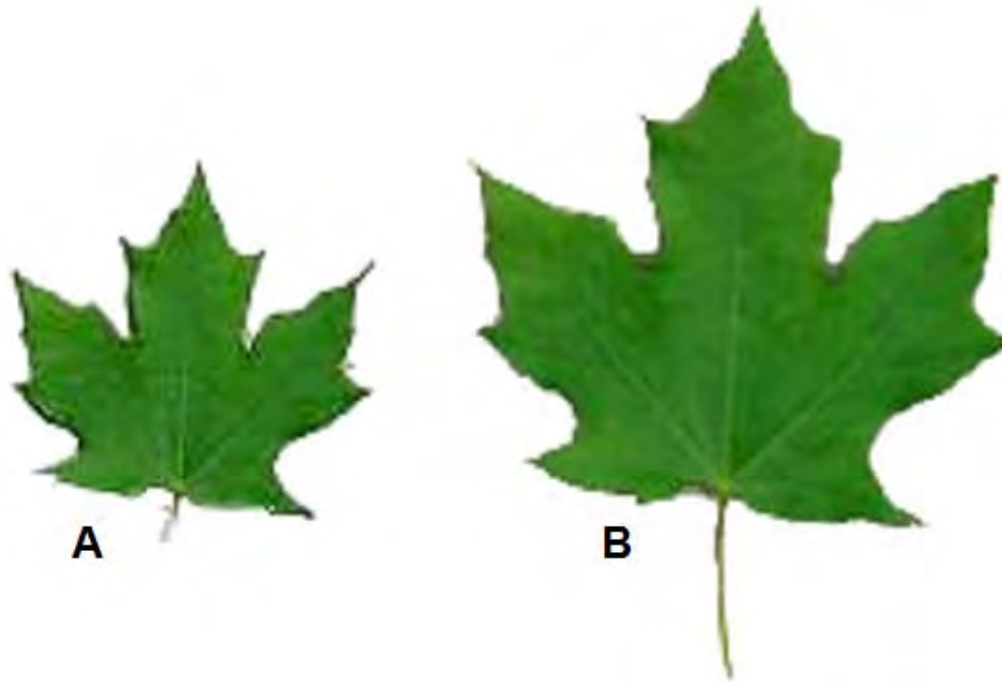
## Exercise 8a: Variation in Leaves & Flowers

**Q3.** Which type of leaves would you expect to have a greater surface area: shade leaves or sun leaves? **CLICK FOR THE ANSWER!**

- ☐ Sun leaves tend to have smaller surface areas than shade leaves.
- ☐ Sun leaves also tend to be thicker than shade leaves, and have multiple layers of energy producing cells.
- ☐ Since sun leaves are exposed to intense light that can penetrate multiple cell layers, sun leaves increase energy production & minimize water loss by growing thicker instead of wider.
- ☐ Shade leaves, meanwhile, do not have to contend with water loss due to exposure to strong wind and light.
- ☐ Instead, they struggle to obtain enough light. In order to increase their exposure to the sun, shade leaves grow larger surface areas.
- ☐ Trees can't consciously alter the way individual leaves grow, so how does this variation occur?
- ☐ Leaf growth is regulated by multiple genes, some of which are activated or inhibited by light or a lack of light.

## Exercise 8a: Variation in Leaves & Flowers

**Q4.** Which of the leaves in the figure below is the sun leaf?



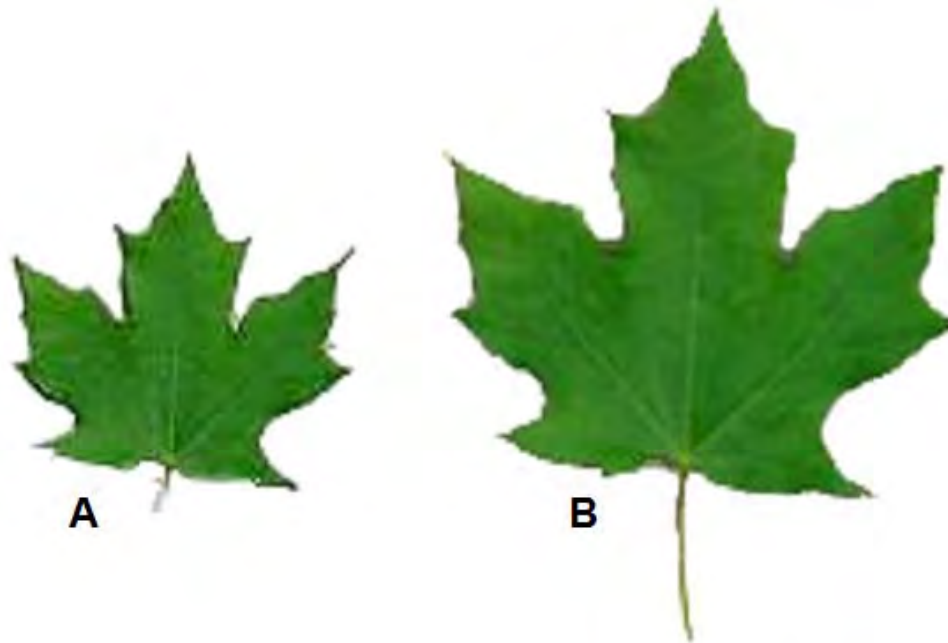
**CLICK FOR THE ANSWER!**

**Leaf A is the sun leaf!**

## Exercise 8a: Variation in Leaves & Flowers

**Q5. How much larger is leaf B's surface area than leaf A's surface area? Come up with a way to estimate the surface area of the leaves and then use your surface area estimates to perform the following calculations. Calculate how many times larger leaf B's surface area is than leaf A's surface area. Calculate the percent difference between the surface areas of leaf A and leaf B.**

**GO TO THE NEXT SLIDE FOR THE SOLUTION!**



## Exercise 8a: Variation in Leaves & Flowers

- ❑ We can calculate how much larger leaf B's surface area is as follows:
- ❑ Measure the width of leaf A at its widest point and the length of leaf A at its longest point. Multiply these two measures to obtain an estimate of leaf area:  $A_A = l \times w$
- ❑ Do the same for leaf B.
- ❑ The ratio of the two areas shows how many times greater the amount of sunlight leaf B can capture compared to leaf A:

$$\frac{A_B}{A_A} = x$$

- ❑ Leaf B is capable of capturing  $x$  times more sunlight than leaf A.
- ❑ We can also calculate the percent difference in the amount of sunlight that the two leaves can capture as follows:

$$\frac{A_B - A_A}{A_A} \times 100 = x$$

- ❑ Leaf B is capable of capturing  $x\%$  more sunlight than leaf A.

## Exercise 8a: Variation in Leaves & Flowers

- ☐ Examine the leaves below. Note that there are four different leaf shapes:



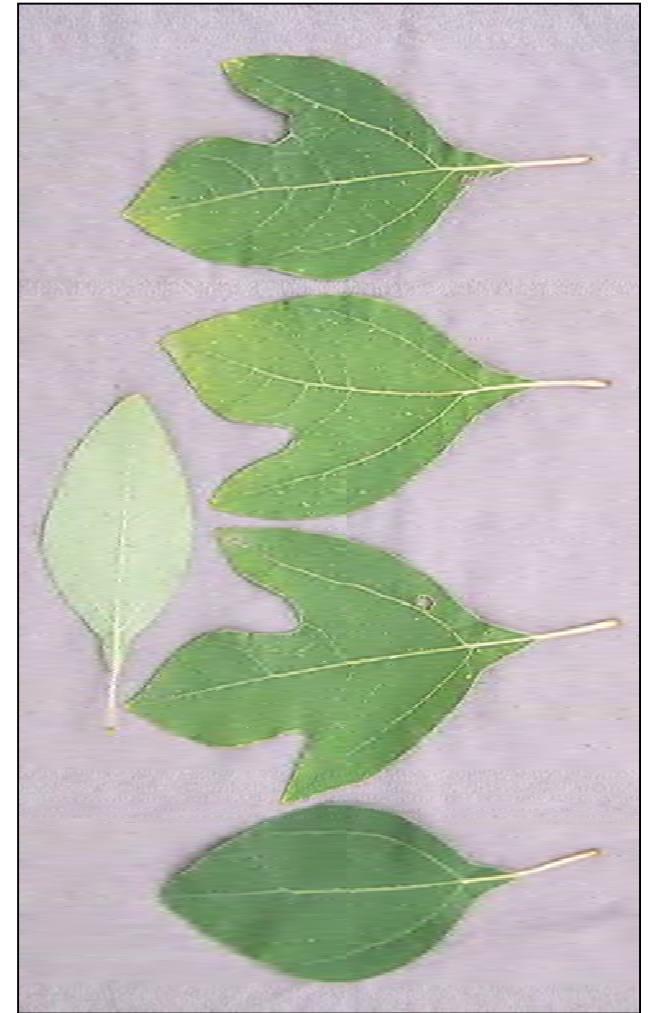
- ☐ Elliptical/ovate (balloon or egg-shaped)
- ☐ three-lobed (two side lobes and one main lobe)
- ☐ two-lobed, left side
- ☐ two-lobed, right side
- ☐ Note that two shapes look like left- & right-handed mittens.
- ☐ Locate each of the four leaf shapes in the figure.

## Exercise 8a: Variation in Leaves & Flowers

- ❑ Sassafras is a tree that produces all four leaf types, often on the same branch!
- ❑ If a trait, such as leaf shape, varies for genetic reasons, then the distinct variants of the trait are called **morphs**, and the trait is said to be **polymorphic** (has many morphs).
- ❑ Thus, using this new terminology we would say that sassafras exhibits a leaf shape polymorphism with four morphs.

**Q6.** Can you think of other examples of polymorphisms?

**Go to the next slides for examples!**





## Exercise 8a: Variation in Leaves & Flowers

- ❑ Other examples of polymorphism include wing colors and patterns within the same species, as in *Heliconius* butterflies.
- ❑ Some plant species, including morning glories (*Ipomoea* sp.) have flower color polymorphism.
- ❑ Some spider species have different body patterns such as the Hawaiian Happy Face spider (*Theridion grallator*), that has several different “faces” on its abdomen.



## Exercise 8a: Variation in Leaves & Flowers

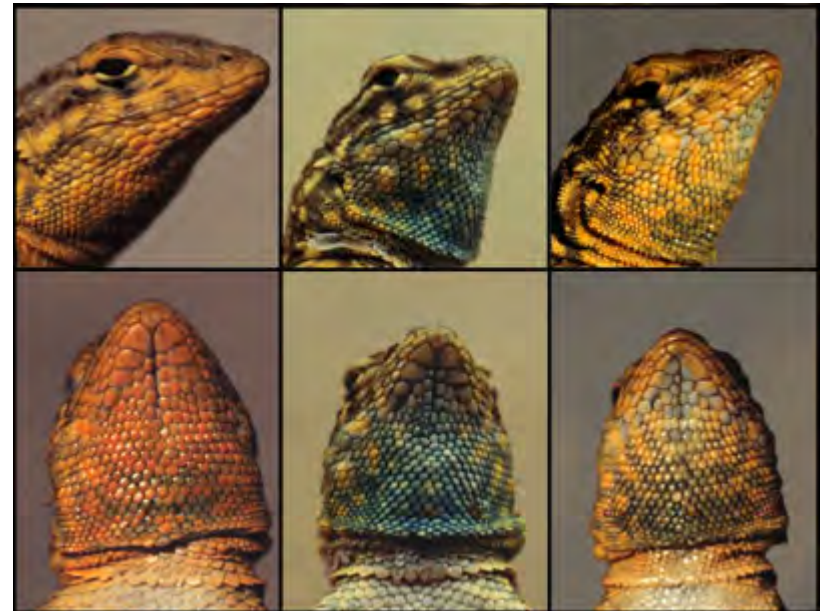
- ❑ Some fish species, such as the three-spined stickleback (*Gasterosteus aculeatus*) are polymorphic with regard to body size and shape.
- ❑ In these sticklebacks, a larger morph is adapted to benthic habitats (on or near the bottom of aquatic habitats), and a smaller morph is adapted to more limnetic (open-water) habitats.
- ❑ Many salamanders within the genus *Plethodon* (like the Southern Red-backed salamander, *Plethodon serratus*) also have two forms: a dark, unstriped “leadback” form, and a reddish, striped “redback” form.





## Exercise 8a: Variation in Leaves & Flowers

- ❑ Some fish (like the round goby, *Neogobius melanostomus*) and lizards (like the side-blotched lizard, *Uta stansburiana*) have different male morphs which use different mating strategies.
- ❑ Large male morphs defend females from other males, but small male morphs look more like females, and are not chased out of larger males' territories.
- ❑ These “sneaker” males can then sneak up on females to mate.
- ❑ These are just a few examples, as polymorphisms can be found in all sorts of other organisms!



## Exercise 8a: Variation in Leaves & Flowers

- ☐ We have learned that leaves can vary in size and shape for a number of reasons.
- ☐ Examine the flowers in the figure below.



- ☐ Do you see many differences between the two flowers of the red lily plant or among the many flowers of purple coneflowers?
- ☐ Though there are numerous species of flowering plants, within a species, of all the parts of a plant, the flower is the least variable.
- ☐ We call traits with little inter-individual variation **conserved traits**.
- ☐ Go on to the next slides to learn why flowers show little variation within a species.

## Exercise 8a: Variation in Leaves & Flowers

- ☐ Flowers house the reproductive organs of the plant.
- ☐ The male organs are called **anthers**.
- ☐ The female organ is called a **pistil**.
- ☐ In order to reproduce, flowering plants need animals called **pollinators**.
- ☐ Pollinators carry pollen produced by the anthers of one plant to the pistil of another plant.
- ☐ In pollination, pollinators assist flowering plants with the production of offspring (in the form of seeds).

## Exercise 8a: Variation in Leaves & Flowers

- ☐ Pollinators are often species-specific, that is, they pollinate a specific set of species.
- ☐ For example, hummingbirds may pollinate morning glories but they do not pollinate daisies.
- ☐ Therefore, it is important that pollinators be able to recognize the flowers of the species they pollinate.
- ☐ If a pollinator visits the wrong type of flower, then any pollen that it leaves behind is wasted.
- ☐ Pollen is very costly to make, and is also species-specific.
- ☐ Seeds will not form if the wrong pollen is delivered to a pistil.
- ☐ Thus the flowers of a particular plant species have little variation.



## Exercise 8b: Variation in Snail Shells

- ☐ 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 way 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.

**Left-handed spiral**



**Right-handed spiral**

## Exercise 8b: Variation in Snail Shells

- ☐ Another way to determine a snail's handedness 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 the figure below for an illustration of shells with left-handed and right-handed spirals.

**Left-handed spiral**

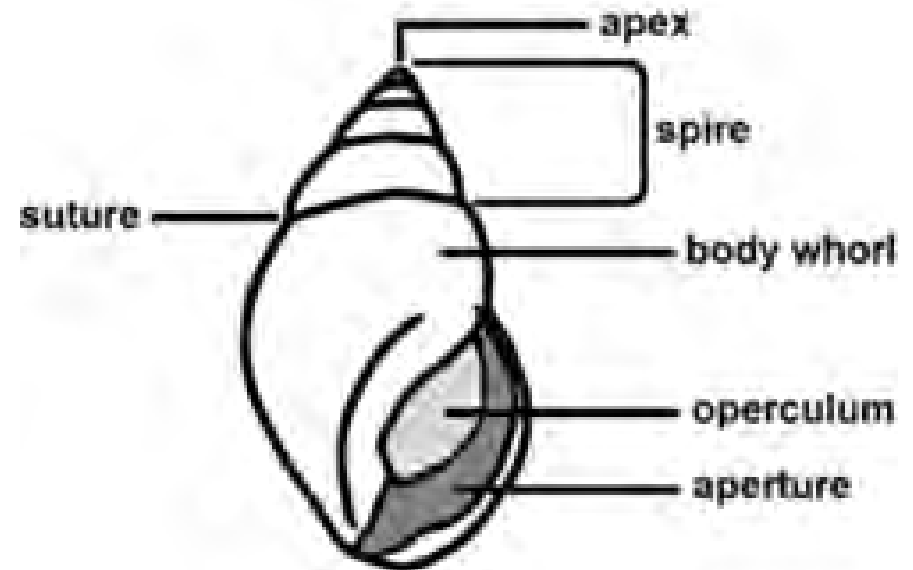


**Right-handed spiral**



## Exercise 8b: Variation in Snail Shells

- ❑ 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 the snail formed before it hatched.
- ❑ Notice the spiral **suture** (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 its shell larger and larger by adding new material as it grew.



## Exercise 8b: Variation in Snail Shells

- ☐ 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?



## Exercise 8b: Variation in Snail Shells

- ☐ 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 on the following slides, & measure this for each shell.

## Exercise 8b: Variation in Snail Shells

- ❑ **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.).
- ❑ **Width and/or height of the aperture (opening)**
- ❑ **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.
- ❑ **Shell width:** With the shell held in the same position as above, measure the greatest straight line distance across the shell.
- ❑ **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.

## Exercise 8b: Variation in Snail Shells

**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.

$$\text{Volume of a cone} = \frac{1}{3}\pi r^2 h$$

$$\text{Volume of a cylinder} = \pi r^2 h$$

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

**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.

$$\text{Area of a circle} = \pi r^2$$

$$\text{Area of an ellipse} = \frac{1}{2}\pi ab$$

- ❑ In the formula for the area of an ellipse, **a** and **b** represent the width and height of the ellipse respectively.

## Exercise 8b: Variation in Snail Shells

- ☐ 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 (# of whorls) |
|------|--------------------------------|
| 1    | 1.25                           |
| 2    | 2.75                           |
| 3    | 3                              |
| 4    | 3.5                            |

- ☐ Now try to answer the following question:

**Q7.** Does your ranking according to apparent size agree with your size measurements? Why might your visual rankings differ than rankings based on your measurements?

## Exercise 8b: Variation in Snail Shells

**Q8. Since the equation for the circumference of a circle is  $C = \pi d$ , and the diameter of a circle is equal to two times its radius ( $d = 2r$ ), how would you solve for the radius to help you calculate the volume?**

**CLICK FOR THE ANSWER!**

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  $2\pi$ , 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.

**Q9. How is a snail's shell volume related to its body size?**

**CLICK FOR THE ANSWER!**

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.

## Exercise 8b: Variation in Snail Shells

- ❑ 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  $\frac{y}{x}$ .

## Exercise 8b: Variation in Snail Shells

**Q10.** What is the factor by which the value of a nickel is less than the value of a dime?

**CLICK FOR THE ANSWER!**

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  $c$ :

$$\begin{aligned}y &= cx \\ 5 &= c(10) \\ c &= \frac{5}{10} = 0.5\end{aligned}$$

**Q11.** What is the factor by which the value of a nickel is less than the value of a quarter?

**CLICK FOR THE ANSWER!**

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

## Exercise 8b: Variation in Snail Shells

**Q12.** What is the factor by which the value of a quarter is greater than the value of a nickel?

**CLICK FOR THE ANSWER!**

$$c = 5$$

**Q13.** 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 \_\_\_\_?

**CLICK FOR THE ANSWER!**

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



## Exercise 8b: Variation in Snail Shells

- ☐ 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 # | Factor by which the whorl number increases<br>(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.

## Exercise 8b: Variation in Snail Shells

- 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.

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

- 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.

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

| Whorl # | Factor by which the whorl number increases<br>(relative to next smaller shell) |
|---------|--|
| 1       | Not applicable   |
| 2       | 2  |
| 2.5     | 1.25   |
| 3.25    |  |
| 3.5     |  |

## Exercise 8b: Variation in Snail Shells

| Whorl # | Factor by which the whorl number increases<br>(relative to next smaller shell) |
|---------|--|
| 1       | Not applicable   |
| 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 8b.2: Thinking about adaptive variation

- ☐ 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 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 at least 2-3 traits that might be related to the lifestyle aspect that you chose. On the following slide are listed 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.

## Exercise 8b.2: Thinking about adaptive variation

### Other measurements:

- ❑ **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.
- ❑ Go to the next slide for a few other ideas of other measurements.

## Exercise 8b.2: Thinking about adaptive variation

- ❑ **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, click [HERE](#) for images, as well as descriptions on how to measure these traits.**

## Exercise 8b.2: Thinking about adaptive variation

### 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?

## Exercise 8b.2: Thinking about adaptive variation

### Further open-ended exploration:

- ☐ Using the shell identification guide on the next slides, 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:
  - ☐ Are the shell traits that you measured 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.



## Guide to Snail Shells from Exercise 8

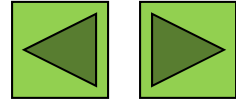
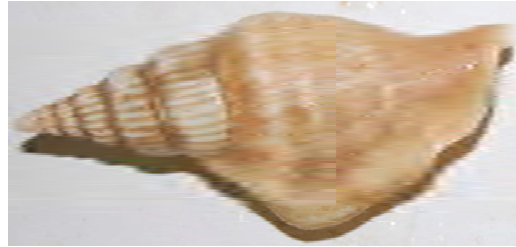


Snails in the genus *Nassarius* are saltwater snails that typically live in shallow waters. They are scavengers that feed on films of algae and detritus (decaying organic material). They are often seen in marine aquariums, where they help keep the glass clean.



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.

## Guide to Snail Shells from Exercise 8

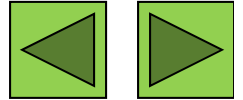
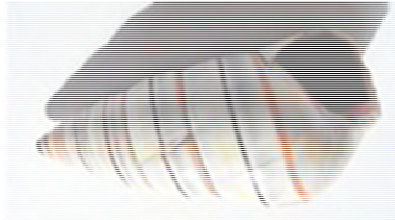


Species in the genus *Strombus* (the true conchs) live on muddy and sandy bottoms in marine habitats, and range from shallow waters to depths of over 160 feet. They are mostly herbivores, feeding on algae and marine plants. An unusual "leaping" motion is common in this genus, in which the conch digs 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.

## Guide to Snail Shells from Exercise 8



Haitian Tree Snails (*Liguus virgineus*, sometimes also called candy cane snails) live in trees, where they feed on fungi, algae, and lichens. 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, which is a term used to describe a period of summer dormancy (similar to hibernation in winter). When the rainy season returns, the snails again become active.



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

## Guide to Snail Shells from Exercise 8



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



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

## Exercise 8b.2: Thinking about adaptive variation

### **Further open-ended exploration (continued):**

- ☐ Your teacher may wish provide you with a scientific review article on the importance of various aspects of land snail shell shape.
- ☐ However, when exploring your question, you 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)?

## Exercise 8b.2: Thinking about adaptive variation

### An optional web-based exercise:

- ☐ Click [HERE](#), 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?



# Suggested Reading



## Grades K-3

*Find the Seashell* - Liza Alexander

*Backyard Explorer Kit with Leaf and Tree Guide* - Rona Beame & Lionel Kalish (Illustrator)

*The Little Yellow Leaf* - Carin Berger

*Seashells by the Seashore* - Marianne Berkes & Robert Noreika (Illustrator)

*Leaves Fall Down: Learning About Autumn Leaves* - Lisa Marie Bullard & Nadine Takvorian

*I Wonder Why Trees Have Leaves and Other Questions About Plants* - Andrew Charman

*A Simple Brown Leaf* - L.J. Davis

*Leaf Man* - Lois Ehlert

*Tell Me, Tree: All About Trees for Kids* - Gail Gibbons

*The Seashell Song* - Susie Jenkin-Pearce & Claire Fletcher (Illustrator)

*My Shell Book* - Ellen Kirk

*We're Going on a Leaf Hunt* - Steve Metzger & Miki Sakamoto (Illustrator)

*Fletcher and the Falling Leaves* - Julia Rawlinson & Tiphonie Beeke (Illustrator)

*Autumn Leaves* - Ken Robbins

*Temperate Deciduous Forests: Lands of Falling Leaves* - Laura Purdie Salas & Jeff Yesh

*Swirl by Swirl: Spirals in Nature* - Joyce Sidman & Beth Krommes (Illustrator)

*Seashells (True Books: Earth Science)* - Ann O. Squire

*Look What I Did with a Leaf! (Naturecraft)* - Morteza E. Sohi

*Leaves* - David Ezra Stein

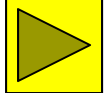
*The Leaf That Wouldn't Leave* - Trish Trinco & Bryan Langdo (Illustrator)

*I Can Name 50 Trees Today!: All About Trees (Cat in the Hat)* - Bonnie Worth, Aristides Ruiz (Illustrator), & Joe Mathieu (Illustrator)

*Fall Leaves Change Color* - Kathleen Weidner Zoehfeld

*What Lives in a Shell?* - Kathleen Weidner Zoehfeld & Helen K. Davie (Illustrator)

## Suggested Reading



### Grades 4-7

*Shell (Eyewitness Books)* - Alex Arthur

*Exploring Statistics in the Elementary Grades: Book 1, Grades K-6*  
- Carolyn Bereska, L. Carey Bolster, Cyrilla A. Bolster, Richard Schaeffer, & Rachel Gage (Illustrator)

*Variation & Classification (Life Science in Depth)* - Ann Fullick

*Seashells in My Pocket: AMC's Family Guide to Exploring the Coast from Maine to Florida* - Judith Hansen & Donna Sabaka (Illustrator)

*Secret Lives of Seashell Dwellers* - Sara Swan Miller

*The Secret Spiral* - Gillian Neimark

*A Wasp is Not a Bee* - Marilyn Singer & Patrick O'Brien (Illustrator)

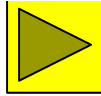
*The Tree of Life* - Peter Sis

*Tree of Life: The Incredible Biodiversity of Life on Earth* - Rochelle Strauss & Margot Thompson

*Animal Kingdom: A Guide to Vertebrate Classification and Biodiversity* - Kathryn Whyman



# Suggested Reading



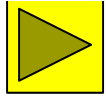
## **Grades 7+**

*Compendium of Seashells: A Full-Color Guide to More than 4,200 of the World's Marine Shells* - R. Tucker Abbott & S. Peter Dance  
*Shells (Smithsonian Handbooks)* - S. Peter Dance  
*Evolution (DK Eyewitness Guide)* - Linda Gamlin  
*Biodiversity* - Dorothy Hinshaw Patent & William Munoz (Illustrator)  
National Audubon Society Field Guide to North American Seashells - National Audubon Society  
*The Biodiversity Crisis: Losing What Counts (American Museum of Natural History Books)* - Michael J. Novacek (Editor)  
*The Art of Shelling: A Complete Guide to Finding Shells and Other Beach Collectibles at Shelling Locations from Florida to Maine* - Chuck Robinson  
*Seashells: Jewels from the Ocean* - Budd Titlow  
*A Natural History of Shells* - Geerat J. Vermeij  
*Data, Graphing, and Statistics Smarts!* - Rebecca Wingard-Nelson

## **All Ages**

*Seashells of the World (Golden Guide)* - R. Tucker Abbott, Herbert Spencer Zim (Editor), & George F. Sandstrom (Illustrator)  
*The World's Most Beautiful Seashells* - Pete Carmichael, Leonard Hill, & Tim Ohr (Editor)  
*Peterson First Guide to Shells of North America* - Jackie Leatherbury Douglass & John Douglass (Illustrator)  
*Seashells* - Josie Iselin & Sandy Carlson  
*National Audubon Society Pocket Guide to Familiar Seashells* - National Audubon Society

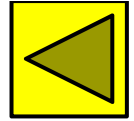
# Suggested Reading



## Scientific Journal Articles (included on Teacher CD)

- Ayoub, N.A., S.E. Riechert, & R.L. Small. 2005. Speciation history of the North American funnel web spiders, *Agelenopsis* (Araneae: Agelenidae): Phylogenetic inferences at the population-species interface. *Molecular Phylogenetics and Evolution* 36:42-57.
- Bruschi, P., P. Grossoni, & F. Bussotti. 2003. Within- and among-tree variation in leaf morphology of *Quercus petraea* (Matt.) Liebl. natural populations. *Trees* 17:164-172.
- Cain, A.J. & P.M. Sheppard. 1954. Natural Selection in *Cepaea*. *Genetics* 39(1):89-116.
- Cotton, P.A., S.D. Rundle, & K.E. Smith. 2004. Trait compensation in marine gastropods: shell shape, avoidance behavior, and susceptibility to predation. *Ecology* 85(6):1581-1584.
- Hugall, A.F. & D. Stuart-Fox. 2012. Accelerated speciation in colour-polymorphic birds. *Nature* 485:631-634.
- Ito, M. 2009. Variation in leaf morphology of *Quercus crispula* and *Quercus dentata* assemblages among contact zones: a method for detection of probable hybridization. *Journal of Forest Resources* 14:240-244.
- Oxford, G.S. & R.G. Gillespie. 2001. Portraits of Evolution: Studies of Coloration in Hawaiian Spiders. *BioScience* 51(7):521-528.
- Tang, X. & S. Huang. 2010. Fluctuating selection by water level on gynoeceum colour polymorphism in an aquatic plant. *Annals of Botany* 106:843-848.

## Links (all underlined text is clickable!)



**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 mollusk shells, shell development, torsion in gastropods, and more!

**The Arthropod Story** – Website from the University of California Berkeley's Museum of Paleontology; contains information on the history and diversity of arthropods, as well as symmetry.

**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:

**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!

**Real Trees 4 Kids** – A great site sponsored by the National Christmas Tree Association with TONS of information on trees for kids, broken down into several pages based on grade level, as well as resources for teachers.

**The Space Place: Sorting Out Trees in the Forest** - Another awesome site from NASA describing how different tree species can even be identified from space with current technology!

**eNature: FieldGuides** - Excellent online field guide that allows you to enter your ZIP code to access field guides to plants and animals in your area!

**The Wonders of the Seas: Mollusks** - A brief introduction on mollusk diversity from the Oceanic Research Group.

**Learner.org Life Science Session 5** - A great teacher resource and lesson ideas on variation, adaptation, and natural selection.

**BBC - Schools Science Clips - Variation** - A fun interactive exercise on natural variation for kids ages 6-7.