Exercise 2

Measurements in Biology

The Metric System and Data Analysis

Learning Objectives

By the end of this exercise you should be able to:

1. Understand the difference between accuracy and precision in measurements.
2. Identify the metric units used to measure length, volume, mass, and temperature.
3. Measure length, volume, mass, and temperature in metric units.
4. Convert one metric unit to another (e.g., grams to kilograms).
5. Use measures of volume and mass to calculate density.
6. Practice the use of simple statistical calculations such as mean, median, range, and standard deviation.
7. Analyze sample data using statistical tools.

Please visit connect.mheducation.com to review online resources tailored to this lab.

Every day we're bombarded with numbers and measurements. They come at us from all directions, including while we're at the supermarket, gas station, golf course, and pharmacy, as well as while we're in our classrooms and kitchens. Virtually every package that we touch is described by a measurement.

Scientists use a standard method to collect data as well as use mathematics to analyze measurements. We must measure things before we can objectively describe what we are observing, before we can experiment with biological processes, and before we can predict how organisms respond, adjust to, and modify their world. Once we have made our measurements, we can analyze our data and look for variation and the sources of that variation. Then we can infer the causes and effects of the biological processes that interest us.

ACCURACY AND PRECISION

Scientists strive to make accurate, precise measurements. The **accuracy** of a group of measurements refers to how closely the measured values agree with the true or correct value. In contrast, the **precision** of a group of measurements refers to how closely the measurements agree with each other. That is, precision is the degree to which the measurements produce the same results, regardless of their accuracy. Measurements that are both accurate and precise are **valid** measurements. Scientists strive to make valid measurements.

Question 1

a. Can measurements be accurate but not precise? Explain.

b. Can measurements be precise but not accurate? Explain.

To help you check your answers, consider an analogy involving shooting arrows at a bull's-eye target (fig. 2.1). In this

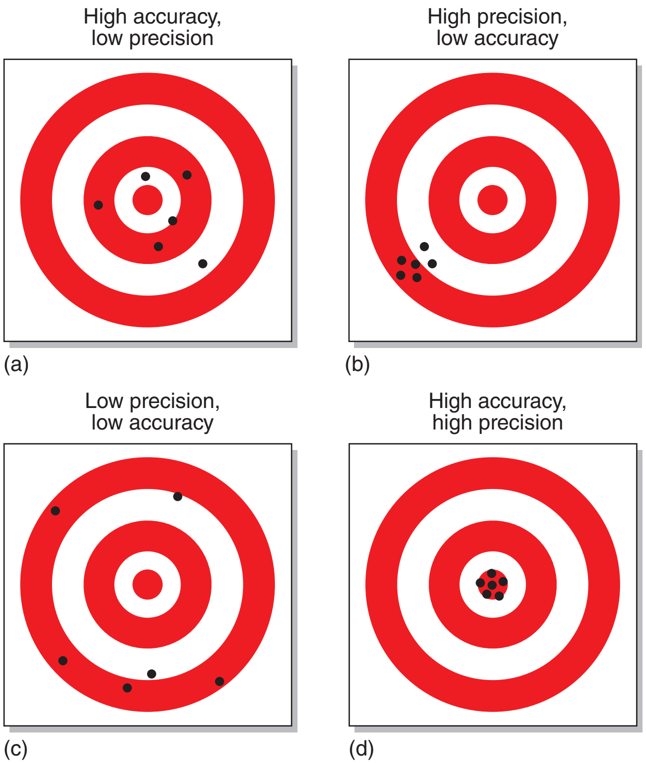

Figure 2.1 Precision and accuracy. Measurements can be (*a*) accurate but not precise, (*b*) precise but not accurate, (*c*) neither precise nor accurate, or (*d*) both precise and accurate. Measurements that are precise and accurate are termed *valid*.

analogy, each arrow would represent a measurement. Accuracy would be the closeness of the arrows to the center of the target; arrows closest to the bull's-eye would be most accurate. Precision would be the size of the cluster of arrows, regardless of how close they are to the center of the target.

THE METRIC SYSTEM

Scientists throughout the world use the **metric system** to make measurements. The metric system is also used in everyday life virtually everywhere except the United States. With few exceptions (e.g., liter bottles of soda), most measurements in the United States use the antiquated English system of pounds, inches, feet, and so on. Check with your instructor about bringing to class common grocery store items with volumes and weights in metric units, or examining those items on display.

Metric measurement is used worldwide in science to improve communication in the scientific community. Scientists make all of their measurements in the metric system; they do not routinely convert from one system to another. When scientists have mixed metric units with English units, the results have often been confusing, and have sometimes been disastrous. For example, in 1999, the $125-million Mars Climate Orbiter was approaching Mars to study the planet's climate. Lockheed Martin Astronautics, which built the spacecraft, gave NASA critical flight information in English units, but software aboard the orbiter expected the data in metric units. As a result, the orbiter was sent into, rather than safely above, the Mars atmosphere, where it disintegrated.

The following conversions will help give you a sense of how some common English units are related to their metric equivalents:

1 inch = 2.5 centimeters
1 foot = 30 centimeters
1 yard = 0.9 meter
1 mile = 1.6 kilometers
1 ounce = 28 grams
1 pound = 0.45 kilogram
1 fluid ounce = 30 milliliters
1 pint = 0.47 liter
1 quart = 0.95 liter
1 gallon = 3.8 liters
1 cup = 0.24 liter

If you want to know more about these conversions, see Appendix II.

This exercise will introduce you to making metric measurements of length, mass, volume, and temperature. During this lab, you should spend your time making measurements, not reading background information. Therefore, *before lab*, *read this exercise carefully to familiarize yourself with the basic units of the metric system*.

Metric units commonly used in biology include:

meter (m)—the basic unit of length
liter (L)—the basic unit of volume
kilogram (kg)—the basic unit of mass
degrees Celsius (°C)—the basic unit of temperature

Unlike the English system with which you are already familiar, the metric system is based on units of ten. This simplifies conversions from one metric unit to another (e.g., from kilometers to meters). This base-ten system is similar to our monetary system, in which 10 cents equals a dime, 10 dimes equals a dollar, and so forth. Units of ten in the metric system are indicated by Latin and Greek prefixes placed before the base units:

Prefix (Latin)		***Division of Metric Unit***	
deci	(d)	0.1	10^{-1}
centi	(c)	0.01	10^{-2}
milli	(m)	0.001	10^{-3}
micro	(μ)	0.000001	10^{-6}
nano	(n)	0.000000001	10^{-9}
pico	(p)	0.000000000001	10^{-12}

Prefix (Greek)		***Multiple of Metric Unit***	
deka	(da)	10	10^{1}
hecto	(h)	100	10^{2}
kilo	(k)	1000	10^{3}
mega	(M)	1000000	10^{6}
giga	(G)	1000000000	10^{9}

Thus, multiply by

0.01 to convert centimeters to meters
0.001 to convert millimeters to meters
1000 to convert kilometers to meters
0.1 to convert millimeters to centimeters

For example, there are 10 millimeters per centimeter. Therefore, to convert 62 centimeters to millimeters,

$$\mathbf{62\ cm \times \frac{10\ mm}{cm} = 620\ mm}$$

In these conversion equations, the units being converted *from* (in this case, centimeters) cancel out, leaving you with the desired units (in this case, millimeters). Also note that when units are converted to *smaller* units, the number associated with the new units will *increase*, and vice versa. For example, 620 meters = 0.620 kilometers = 620,000 millimeters = 62,000 centimeters.

Question 2
Make the following metric conversions:

1 meter =______centimeters =______millimeters

92.4 millimeters =______meters =______centimeters

10 kilometers =______meters =______decimeters

82 centimeters =______meters =______millimeters

3.1 kilograms =______grams =______milligrams

281 milliliters =______liters =_______deciliters

35 millimeters =_____centimeters =_______meters

Length and Area

The **meter** (m) is the basic unit of length. Units of area are squared units (i.e., two-dimensional) of length.

1 m = 100 cm = 1000 mm = 0.001 km =1 × 10^{-3} km
1 km = 1000 m = 10^3 m
1 cm = 0.01 m = 10^{-2} m = 10 mm
470 m = 0.470 km
1 cm^2 = 100 mm^2 (i.e., 10 mm × 10 mm = 100 mm^2)

To help you appreciate the magnitudes of these units, here are the lengths and areas of some familiar objects:

Length	
Housefly	0.5 cm
Diameter of penny	1.9 cm
Diameter of baseball	7.4 cm
Soda can	12.2 cm
Toyota Camry	4.7 m
Mt. Everest	8848 m

Area	
Credit card	46 cm^2
Total skin area of adult human male	1.8 m^2
Ping-pong table	4.18 m^2
Surface area of human lungs	80 m^2
Football field (goal line to goal line)	4459 m^2
Central Park (New York City)	3.4 km^2

Procedure 2.1 **Make metric measurements of length and area**

Most biologists measure lengths with metric rulers or metersticks.

1. Examine intervals marked on the metric rulers and metersticks available in the lab.

2. Make the following measurements. Be sure to include units for each measurement.

Length of this page __________
Width of this page __________
Area of this page (Area = Length × Width) __________
Your height __________
Thickness of this manual __________
Height of a 200-mL beaker __________
Height of ceiling __________
Height of your chair __________
Length of your cell phone __________

Question 3
What are some potential sources of error in your measurements?

Volume

Volume is the space occupied by an object. Units of volume are cubed (i.e., three-dimensional) units of length. The liter (L) is the basic unit of volume.

1 L = 1000 cm^3 = 1000 mL
1 L = 0.1 m × 0.1 m × 0.1 m
1 cm^3 = 0.000001 m^3

To help you appreciate the magnitudes of these units, here are the volumes of some familiar objects:

Chicken egg	60 mL
Coke can	355 mL
One breath of air	500 cm^3

Scientists often measure volumes with pipets and graduated cylinders. Pipets are used to measure small volumes, typically 25 mL or less. Liquid is drawn into a pipet using a bulb or pipet pump (fig. 2.2). Never pipet by mouth.

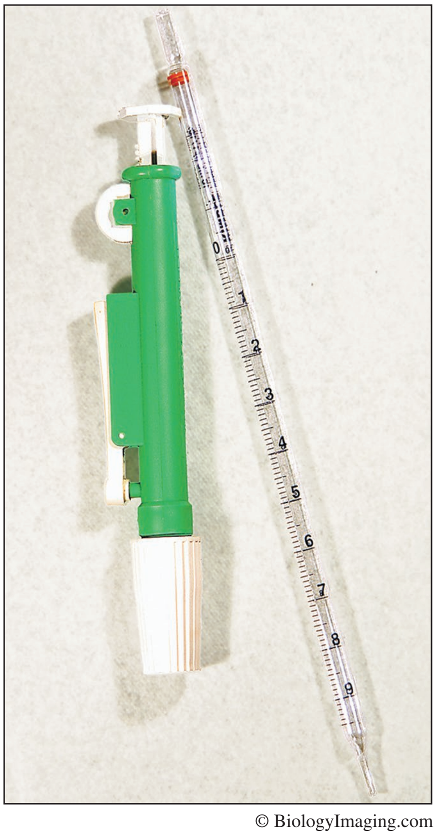

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Figure 2.2 A pipet is used to extract and dispense volumes of liquid. A suction device (shown in green on the left) draws fluid into the pipet, and graduated markings on the pipet allow precise measurement of a fluid's volume. Never use your mouth to suck fluid into a pipet.

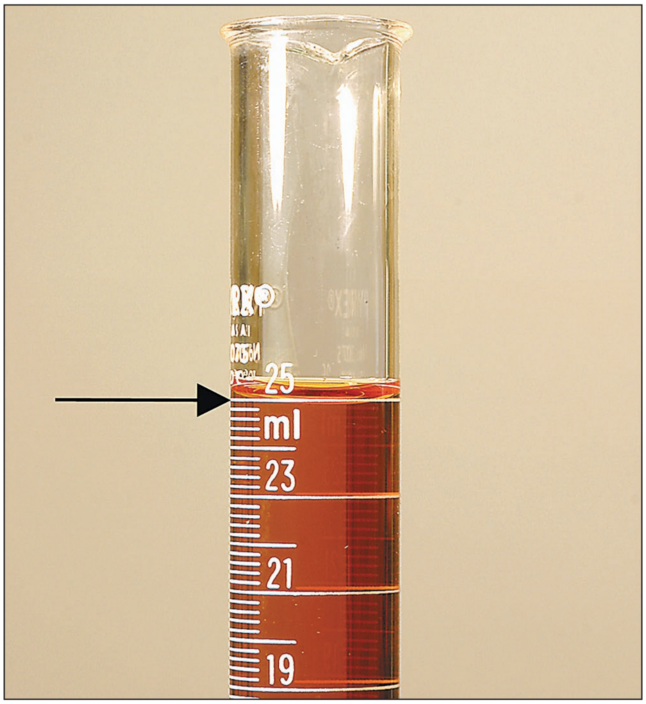

Figure 2.3 When measuring the volume of liquid in a graduated cylinder, always measure at the bottom of the meniscus. The bottom of the meniscus in this photograph is indicated by the arrow. The correct volume is 25 mL.

Graduated cylinders are used to measure larger volumes. To appreciate how to make a measurement accurately, pour 40–50 mL of water into a 100-mL graduated cylinder, and observe the interface between the water and air. This interface, called the **meniscus,** is curved because of surface tension and the adhesion of water to the sides of the cylinder. When measuring the liquid in a cylinder such as a graduated cylinder, always position your eyes level with the meniscus and read the volume at the lowest level (fig. 2.3).

Procedure 2.2 **Make metric measurements of volume**

1. Biologists often use graduated cylinders to measure volumes. Locate the graduated cylinders available in the lab to make the following measurements. Determine what measurements the markings on the graduated cylinder represent. Be sure to include units for each measurement.
2. Measure the milliliters needed to fill a cup (provided in the lab). ________________
3. Measure the liters in a gallon. _______________

Procedure 2.3 **Measure the volume of a solid object by water displacement**

1. Obtain a 100-mL graduated cylinder, a thumb-sized rock, and a glass marble.
2. Fill the graduated cylinder with 70 mL of water.
3. Gently submerge the rock in the graduated cylinder. Notice that the volume of the contents rises.
4. Carefully observe the meniscus of the fluid and record its volume.
5. Calculate and record the volume of the rock by subtracting the original volume (70 mL) from the new volume.

   Rock volume ____________
6. Repeat steps 2–5 to measure and record the volume of the marble.

   Marble volume ____________

Biologists use pipets to measure and transfer small volumes of liquid from one container to another. The following procedure will help you appreciate the usefulness of pipets.

Procedure 2.4 **Learn to use a pipet**

1. Add approximately 100 mL of water to a 100-mL beaker.
2. Use a 5-mL pipet with a bulb or another filling device provided by your instructor to remove some water from the beaker.
3. Fill the pipet to the zero mark.
4. To read the liquid level correctly, your eye must be directly in line with the bottom of the meniscus.
5. Release the liquid into another container.

Question 4
What volume of liquid did you measure?

Mass

The **kilogram** (kg) is the basic unit of mass.[1] A kilogram equals the mass of 1000 cubic centimeters (cm^3) of water at 4°C. Similarly,

$$\mathbf{1\ kg = 1000\ g = 10^3\ g \qquad 1\ mg = 0.001\ g = 10^{-3}\ g}$$

Here are the masses of some familiar objects:

Housefly	12 mg	9V battery	40 g
Hummingbird	1.6 g	Human heart	300 g
Ping-pong ball	2.45 g	Basketball	0.62 kg
Quarter	6.25 g		

Biologists usually measure mass with a top-loading balance or a triple-beam balance (fig. 2.4). Locate the triple-beam balances or top-loading electronic balances in the lab. Triple-beam balances get their names from their three

1 *Remember that mass is not necessarily synonymous with weight. Mass measures an object's* **potential** *to interact with gravity, whereas weight is the force exerted by gravity on an object. Thus, a weightless object in outer space has the same mass as it has on earth.*

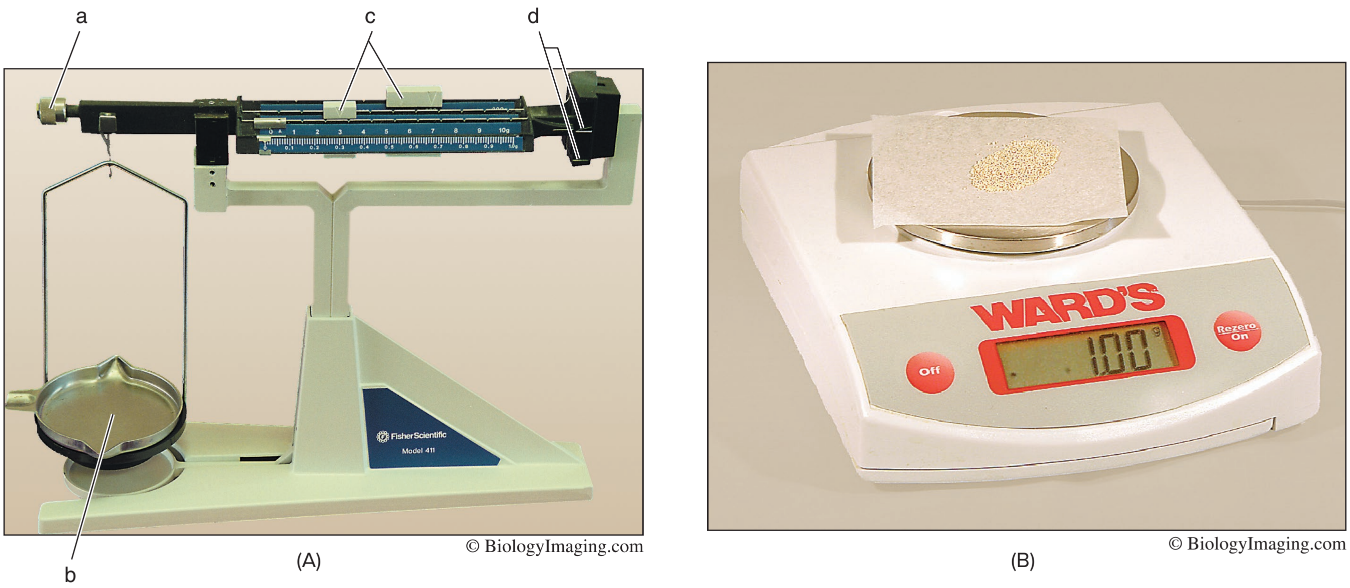

Figure 2.4 Biologists use balances to measure mass. (A) The parts of a triple-beam balance include the (*a*) zero-adjustment knob, (*b*) measuring pan, (*c*) movable masses on horizontal beams, and (*d*) balance marks. (B) A top-loading balance has a measuring pan, a power switch, and a zero calibration ("Tare") button.

horizontal beams. Suspended from each of the three beams are movable masses. Each of the three beams of the balance is marked with graduations: the closest beam has 0.1-g graduations, the middle beam has 100-g graduations, and the farthest beam has 10-g graduations.

Procedure 2.5 Make metric measurements of mass

1. Before making any measurements, clean the weighing pan and move all of the suspended weights to the far left. The balance marks should line up to indicate zero grams; if they do not, turn the adjustment knob until they do. Measure the mass of an object by placing it in the center of the weighing pan and moving the suspended masses until the beams balance. The mass of the object is the sum of the masses indicated by the weights on the three beams.
2. If you're using an electronic balance, turn on the balance and let it warm up for 5 minutes. Wait until the display reads 0.0 g; if the display does not read 0.0 g, press the "Tare" button to reset the display to 0.0 g. If you are weighing an object such as a coin or pencil, place the object on the measuring pan. After the display has stabilized, read and record the object's mass.
3. If you are weighing a liquid, powder, or similar specimen, place an empty beaker (in which you will place the liquid) or a piece of weighing paper (on which you will place the powder) on the balance's measuring pan. After the display has stabilized, press the "Tare" button to reset the display to 0.0 g. Place the liquid in the beaker (or the powder on the weighing paper). After the display has stabilized, read and record the mass.
4. Measure the masses of the following items. Be sure to include units for each measurement.

   Penny _______________

   Paper clip _______________

   Pencil _______________

   Rock (used in procedure 2.3) _____________

   100-mL beaker (empty) _____________

   100-mL beaker containing 50 mL of water _________

Question 5

a. **Density** is mass per unit volume. Use data that you've gathered to determine the density of water at room temperature.

Density of water = (mass/volume) = __________

b. What is the density of the wooden pencil? Does it float? Why?

c. What is the density of the rock? Does it sink? Why?

Temperature

Temperature is the measure of the kinetic energy of molecules—that is, the amount of heat in a system. Biologists measure temperature with a thermometer calibrated in degrees Celsius (°C). The Celsius scale is based on water freezing at 0°C and boiling at 100°C. You can interconvert °C and degrees Fahrenheit (°F) by using the formula 5(°F) = 9(°C) + 160. Here are some typical temperatures:

−20°C	temperature in a freezer
−18°C	mixture of ice and salt
0°C	water freezes
4°C	temperature in a refrigerator
22°C	room temperature
30.6°C	butter melts
37°C	human body temperature
40°C	a hot summer day
50°C	hottest day on record in Phoenix, AZ
71°C	flash pasteurization of milk
75°C	hot coffee
100°C	water boils
260°C	broiler temperature

Procedure 2.6 **Make metric measurements of temperature**

1. Obtain a thermometer in the lab. Handle the thermometer with care. If it breaks, notify your instructor immediately.
2. Determine the range of the temperatures that can be measured with your thermometer by examining the scale imprinted along the barrel of the thermometer.
3. Measure the following temperatures:

   Room temperature ____________ °C

   Cold tap water ____________ °C

   Hot tap water ____________ °C

   Inside refrigerator ____________ °C

UNDERSTANDING NUMERICAL DATA

Statistics offer a way to organize, summarize, and describe data—the data are usually samples of information from a much larger population of values. Statistics and statistical tests allow us to analyze the sample and draw inferences about the entire population. Consequently, the use of statistics enables us to make decisions even though we have incomplete data about a population. Although this may seem unscientific, we do it all the time; for example, we diagnose diseases with a drop of blood. Decisions are based on statistics when it is impossible or unrealistic to analyze an entire population.

Let's say that you want to know the mass of a typical apple in your orchard. To obtain this information, you could analyze one apple, but how would you know that you'd picked a "typical" sample? After all, the batch from

Significant Figures

Let's suppose that you're measuring the length of a bone, as shown in figure 2.5. How would you record this length—as 8 cm? 8.3 cm? 8.33 cm? 8.33333 cm? To answer this question, you need to know something about significant figures.

Significant figures are the number of figures required to record a measurement so that only the last digit in the number is in doubt. For example, if the ruler you're using is calibrated only in centimeters and you find that the object you're measuring is between 8 and 9 cm long (fig. 2.5), then you should estimate your measurement only to a tenth of a centimeter. That is, a measurement of 8.3 cm is acceptable, but 8.33 is not because it implies a precision that did not exist in the equipment you used to make the measurement. If, however, your ruler was calibrated in millimeters, then 8.33 cm would be acceptable. Remember this: When recording measurements, include all of the digits you are sure of plus an estimate to the nearest one-tenth of the next smaller digit.

Here are some other guidelines for using the correct number of significant figures in your measurements:

When adding or subtracting measurements, the answer should have no more precision than the measurement having the least number of significant figures. For example, suppose the air temperature in an incubator drops from 8.663°C to 8.2°C. This is a difference of 8.663°C – 8.2°C = 0.5°C, not 0.463°C. If the second temperature reading had been 8.200°C, then the correct answer would have been 0.463°C.

When converting measurements from one set of units to another, do not introduce precision that is not present in the first number. For example, 8.3 cm = 83 mm, not 83.0 mm.

When manipulating two measurements simultaneously, the precision of the final measurement should not exceed that of the least number of significant figures. For example, the calculation for the mass of 17.2 mL of water is 17.2 mL × 0.997821 g mL^{-1} = 17.2 g, not 17.162521 g.

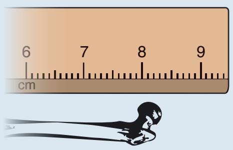

Figure 2.5 How long is this bone? 8 cm? 8.3 cm? 8.33 cm?

which you chose the apple may contain many others, each a little different. You'd get a better estimate of "typical" if you increased your sample size to a few hundred apples, or even to 10,000. Or, better yet, to 1,000,000.

The only way to be certain of your conclusions would be to accurately measure all the apples in your orchard. This is impossible, so you must choose apples that *represent* all of the other apples—that is, you must be working with a *representative sample*. A statistical analysis of those sample apples reduces the sample values to a few characteristic measurements (e.g., mean mass). As you increase the size of the sample, these characteristic measurements provide an ever-improving estimation of what is "typical."

There are a variety of software programs that perform statistical analyses of data; all you have to do is enter your data into a spreadsheet, select the data that you want to analyze, and perform the analysis. Although these software packages save time and can increase accuracy, you still need to understand a few of the basic variables that you'll use to understand your numerical data. We'll start with the mean and median:

The **mean** is the arithmetic average of a group of measurements. Chance errors in measurements tend to cancel themselves when means are calculated for relatively large samples; a value that is too high because of random error is often balanced by a value that is too low for the same reason.

The **median** is the middle value of a group of measurements.

The median is less sensitive to extreme values than is the mean. To appreciate this, consider a sample consisting of 14 leaves having the following lengths (all in mm):

80 69 62 74 69 51 45 40 9 64 65 64 61 67

The mean length is 58.6 mm. However, none of the leaves are that length, and most of the leaves are longer than 60 mm. In biology, the mean is usually preferred to the median when reporting descriptive statistics.

Question 6

a. Does the mean always describe the "typical" measurement? Why or why not?

b. What information about a sample does a mean *not* provide?

Determine the median by arranging the measurements in numerical order:

9 40 45 51 61 63 64 64 65 67 69 69 73 80

The median is between the seventh and eighth measurement: 64 mm. In this sample, the mean differs from the median.

Question 7

a. What is responsible for this difference between the mean and median?

b. How would the median change if the 9-mm-long leaf was not in the sample?

c. How would the mean change if the 9-mm-long leaf was not in the sample?

d. Consider these samples:

Sample 1: 25 35 32 28

Sample 2: 15 75 10 20

What is the mean for Sample 1? _____________

What is the mean for Sample 2? _____________

In most of the exercises in this manual, you'll have time to make only one or two measurements of a biological structure or phenomenon. In these instances, a mean may be the only descriptor of the sample. However, if your class combines its data so that there are many measurements, you'll

Hints for Using the Metric System

1. Use decimals, not fractions (e.g., 2.5 m, not $2\frac{1}{2}$ m).
2. Express measurements in units requiring only a few decimal places. For example, 0.3 m is more easily manipulated and understood than 300000000 nm.
3. When measuring pure water, the metric system offers an easy and common conversion from volume measured in liters to volume measured in cubic meters to mass measured in grams: 1 mL = 1 cm^3 = 1 g.
4. The metric system uses symbols rather than abbreviations. Therefore, do not place a period after metric symbols (e.g., 1 g, not 1 g.). Use a period after a symbol only at the end of a sentence.
5. Do not mix units or symbols (e.g., 9.2 m, not 9 m 200 mm).
6. Metric symbols are always singular (e.g., 10 km, not 10 kms).
7. Except for degrees Celsius, always leave a space between a number and a metric symbol (e.g., 20 mm, not 20mm; 10°C, not 10° C).
8. Use a zero before a decimal point when the number is less than one (e.g., 0.42 m, not .42 m).

need to know how to do a couple of other calculations so that you understand the variation within your sample.

Variability

As you can see, the samples in Question 7d are different, but their means are the same. Thus, the mean does not reveal all there is to know about these samples. To understand how these samples are different, you need other statistics: the range and standard deviation.

The **range** is the difference between the extreme measurements (i.e., smallest and largest) of the sample. In Sample 1, the range is 35 − 25 = 10; in Sample 2 the range is 75 − 10 = 65. The range provides a sense of the variation of the sample, but the range can be artificially inflated by one or two extreme values. Notice the extreme values in the sample of leaf measurements previously discussed. Moreover, ranges do not tell us anything about the measurements between the extremes.

Question 8

a. Could two samples have the same mean but different ranges? Explain.

Rounding Numbers

Do not change the value of the last significant digit if that digit is followed by a number that is less than 5. For example, if two significant figures are required, 6.449 rounds to 6.4, 66.449 rounds to 66, 66.641 rounds to 67, and 6.591 rounds to 6.6. Here is how an original measurement of 49.5149 rounds to various numbers of significant figures:

Five significant figures:	49.515
Four significant figures:	49.51
Three significant figures:	49.5
Two significant figures:	50
One significant figure:	50

Statisticians disagree on what to do when the number following the last significant figure is exactly 5, as in 89.5 (and, in this case, the precision is limited to two significant figures). Some round the measurement to the higher number, while others claim that doing so introduces bias into the data. You can decide which approach to take, but be consistent.

b. Could two samples have the same range but different means? Explain.

The **standard deviation** indicates how measurements vary about the mean. The standard deviation is easy to calculate. Begin by calculating the mean, measuring the deviation of each sample from the mean, squaring each deviation, and then summing the deviations. This summation results in the **sum of squared deviations.** For example, consider a group of shrimp that are 22, 19, 18, and 21 cm long. The mean length of these shrimp is 20 cm.

Sample Value	*Mean*	*Deviation*	*(Deviation)²*
22	20	2	4
19	20	−1	1
21	20	1	1
18	20	−2	4

Sum of Squared Deviations = 10

The summary equation for the sum of squared deviations is:

$$\textbf{Sum of squared deviations} = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

where

N = **total number of samples**

$\bar{x}$ = **the sample mean**

x_i = **measurement of an individual sample**

This formula is simple. The summation sign ($\sum_{i=1}^{N}$) means to add up all the squared deviations from the first one (i = 1) to the last one (i = N). The sum of squared deviations (10) divided by the number of samples minus one (4 − 1 = 3) produces a value of 10/3 = 3.3 cm^2 (note that the units are centimeters squared). This is the **variance:**

$$\textbf{Variance} = \frac{\textbf{sum of squared deviations}}{N-1}$$

The square root of the variance, 1.8 cm, equals the **standard deviation (SD):**

$$\textbf{SD} = \sqrt{\textbf{Variance}} = \sqrt{\textbf{3.3}} = \textbf{1.8}$$

The standard deviation is usually reported with the mean in statements such as, "The mean length of the shrimp was 20 ± 1.8 cm."

The standard deviation helps us understand the spread or variation of a sample. For many distributions of measurements, the mean ± 1 SD includes 68% of the measurements, whereas the mean ± 2 SD includes 95% of the measurements.

Procedure 2.7 **Gather and analyze data statistically**

1. Use a meterstick or tape measure to measure your height in centimeters. Record your height here: __________________cm
2. Record your height and gender (male or female) on the board in the lab.
3. After all of your classmates have reported their heights, calculate the following:

   Size of sample

   All classmates ____________________

   Male classmates ___________________

   Female classmates _________________

   Mean height

   All classmates ____________________

   Male classmates ___________________

   Female classmates _________________

   Median height

   All classmates ___________________

   Male classmates __________________

   Female classmates ________________

   Range

   All classmates _________ to _________

   Male classmates __________ to _________

   Female classmates__________ to _________

   Standard deviation

   All classmates ± _________

   Male classmates ± _________

   Female classmates ± _________

If there is sufficient time, obtain a newspaper that advertises cars, groceries, or other common commodities. Choose one example (e.g., new cars) and determine its average price (e.g., determine the average price of a new car).

Question 9

a. What does your calculation tell you?

b. What are the limitations of your sample?

Your instructor may ask you to do other statistical tests, such as Student's *t*, chi-square, and analysis of variance (ANOVA). The type of test you'll do will depend on the amount and type of data you analyze, as well as the hypotheses you are trying to test.

INVESTIGATION

Variation in the Areas and Shapes of Leaves

Observation: Leaves, which are the primary photosynthetic organ of most plants, are adapted for absorbing light. This involves exposing large surface areas to the environment.

Question: How does the surface area and shape of leaves vary on different parts of plants?

a. Establish a working lab group and obtain Investigation Worksheet 2 from your instructor.

b. Discuss with your group well-defined questions relevant to the preceding observation and question. If leaves are not available from outdoor plants (e.g., during winter), use the plants provided by your instructor that were grown indoors. Choose and record your group's best question for investigation.

c. Translate your question into a testable hypothesis and record it.

d. Outline on Worksheet 2 your experimental design and supplies needed to test your hypothesis. Ask your instructor to review your proposed investigation.

e. Conduct your procedures, record your data, answer your question, and make relevant comments.

f. Discuss with your instructor any revisions to your questions, hypothesis, or procedures. Repeat your work as needed.

Questions for Further Thought and Study

1. What are the advantages and disadvantages of using the metric system of measurements?

2. Why is it important for all scientists to use a standard system of measures rather than the system that may be most popular in their home country or region?

3. Do you lose or gain information when you use statistics to reduce a population to a few characteristic numbers? Explain your answer.

4. Suppose that you made repeated measurements of your height. If you used good technique, would you expect the range to be large or small? Explain your answer.

5. Suppose that a biologist states that the average height of undergraduate students at your university is 205 cm plus or minus a standard deviation of 17 cm. What does this mean?

6. What does a small standard deviation signify? What does a large standard deviation signify?

7. It is possible to make a perfectly precise measurement? Explain.

8. When in our everyday lives do we *not* want precise measurements?