The Importance of MEASUREMENT

Scientists use many skills as they investigate the world around them. They make observations by gathering information with their senses. Some observations are simple. For example, a simple observation would be figuring out the color or texture of an object. However, if scientists want to know more about a substance, they may need to take measurements.

Measurement is perhaps one of the most fundamental concepts in science. Without the ability to measure, it would be difficult for scientists to conduct experiments or form theories. Not only is measurement important in science and the chemical industry, it is also essential in farming, engineering, construction, manufacturing, commerce, and numerous other occupations and activities.

The word “measurement” comes from the Greek word “metron,” which means “limited proportion.” **Measurement** is a technique in which properties of an object are determined by comparing them to a standard.

Measurements require tools and provide scientists with a quantity. A **quantity** describes how much of something there is or how many there are. A good example of measurement is using a ruler to find the length of an object. The object is whatever you are measuring, the property you are trying to determine is the object’s length, and the standard you are comparing the object’s length to is the ruler.

In general, scientists use a system of measurement still commonly referred to as the “metric system.” The metric system was developed in France in the 1790s and was the first standardized system of measurement. Before that time, people used a variety of measurement systems.

In 1960, the metric system was revised, simplified, and renamed the Système International d’Unites (International System of Units) or **SI system** (meters, kilograms, etc.). This system is the standard form of measurement in almost every country around the world, except for the United States, which uses the U.S. customary units system (inches, quarts, etc.). The SI system is, however, the standard system used by scientists worldwide, including those in the United States.

There are several properties of matter that scientists need to measure, but the most common properties are length and mass. **Length** is a measure of how long an object is, and **mass** is a measure of how much matter is in an object. Mass and length are classified as base units, meaning that they are independent of all other units. In the SI system, each unit of measure has a base unit.

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The seven base units of the SI system are listed in the table below.

Measure	Base Unit
Length	**Meter (m)**
Mass	**Kilogram (kg)**
Time	**Second (s)**
Temperature	**Kelvin (K)**
Amount of substance	**Mole (mol)**
Electric current	**Ampere (A)**
Luminous intensity	**Candela (cd)**

Other SI units have been derived from the seven base units.
The table below lists some common derived units.

Measure	Derived Unit	Symbol	Base Units
Volume	**Liter**	**L**	$10^{-3} \times m^3$
Force	**Newton**	**N**	$kg \times m/s^3$
Energy, work	**Joule**	**J**	$N \times m$
Pressure	**Pascal**	**Pa**	N / m^3
Frequency	**Hertz**	**Hz**	$1 / s$

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Some things scientists want to measure may be very large or very small. The SI, or metric, system is based on the principle that all quantities of a measured property have the same units, allowing scientists to easily convert large and small numbers. To work with such large or small numbers, scientists use metric prefixes. Prefixes can be added to base units and make the value of the unit larger or smaller. For example, all masses are measured in grams, but adding prefixes, such as milli- or kilo-, alters the amount. Measuring a human's mass in grams would not make much sense because the measurement would be such a large number. Instead, scientists use kilograms because it is easier to write and say that a human has a mass of 90 kilograms than a mass of 90,000 grams. Likewise, one kilometer is 1,000 meters, while one millimeter is 0.001 meters. The table below lists some common prefixes and the quantities they represent.

Prefix	Symbol	Numerical Value
tera	T	10^{12} (1,000,000,000,000)
giga	G	10^{9} (1,000,000,000)
mega	M	10^{6} (1,000,000)
kilo	k	10^{3} (1,000)
hecto	h	10^{2} (100)
deca	da	10^{1} (10)
NO PREFIX	--	10^{0} (1)
deci	d	10^{-1} (0.1)
centi	c	10^{-2} (0.01)
milli	m	10^{-3} (0.001)
micro	µ	10^{-6} (0.000001)
nano	n	10^{-9} (0.000000001)
pico	p	10^{-12} (0.000000000001)

New scientific instruments have allowed scientists to measure even smaller and larger amounts. Therefore, additional prefixes have been added over the years, such as femto- (10^{-15}) and exa- (10^{18}).

When scientists take measurements, they generally have two goals—accuracy and precision. **Accuracy** means to get as close as possible to the true measurement (true value) of something. **Precision** means to be able to take the same measurement and get the same result repeatedly.

Unfortunately, measurement is never 100% precise or accurate, so the true value measure of something is never exactly known. This uncertainty is a result of error. **Error** is a concept that is naturally associated with measuring because measurement is always a comparison to a standard. Manually measuring something always involves uncertainty because it is based on judgment. If two people use a ruler to measure how tall a plant is, it may look like 20 cm to one person and 18 cm to the other.

To increase the accuracy of a measurement, and therefore reduce error, an object should always be measured more than once. Taking multiple measurements and then determining the average measurement increases the likelihood that you have the exact measurement. For example, when measuring an object, you determine its length to be 10.50 cm; when you measure it again, you get a measurement of 10.70 cm. If you average these measurements, you get 10.60 cm. The length of the object is *most likely* closer to 10.60 cm than it is to either 10.50 cm or 10.70 cm.

There are two main types of error—random error and systematic error. **Random error** is not controllable. As the name suggests, the occurrence of random errors is random and due to chance. Alternatively, **systematic errors** are controllable and have a known cause. A systematic error can result from many things, such as instrument error, method error, or human error. Systematic errors can usually be identified and reduced or even eliminated.

PRACTICE MEASUREMENT!

Using the background information provided previously, introduce students to measurement with the easy activity below.

1. Have students (in groups or individually) measure the length, width, and height of their textbook. (Make sure students are measuring the same textbook.)
2. As the students take their measurements, have them record the numbers—with units!—e.g., 28.1 centimeters. Then have the students report their measurements to the class by writing their findings on a whiteboard or chalkboard.
3. After pooling all of their measurements, the students should notice that their recordings vary. Explain the reasons why there are differing measurements based on the information on error included on page 10.
4. After discussing error in measurement, the students (or teacher) should calculate the average measurement for the length, width, and height of the textbook. Discuss accuracy and precision with the class. (You can also have all the students take their measurements three times to test their own precision.)
5. With these measurement averages, teach them how to calculate the volume of the book. **Volume** is defined as the amount of space an object occupies. The volume of a rectangular solid can be calculated by measuring the length, width, and height of an object and then multiplying those measurements together (volume = length × width × height).

MODIFICATION/EXTENSION

1. Have 3 or 4 students volunteer to use a plastic container to collect water from a water fountain for 5 seconds each. (Measure time using a stopwatch.)
2. Then, have each volunteer pour that water into separate graduated cylinders to determine how much water they have collected. (Measure volume and record the measurements).
3. Write down each volume on the board and ask all the students to calculate the average volume of water used. (Discuss what may account for the differences. Answers may include human error in measuring time or volume, etc.)
4. Ask the students to multiply this number by the number of students in the classroom to figure out how much water would have been used if all the students collected the water.
5. Finally, have the students convert that number into liters.

EXPANDED MODIFICATION/EXTENSION TO DISCUSS WATER CONSERVATION

1. Place a rectangular plastic container under the water fountain faucet so that it covers the drain. Then, have 3 or 4 volunteers drink from the fountain for 5 seconds each. (Make sure the water that the students aren't consuming is being collected in the container.)
2. Then, have the students pour the water from the container into a graduated cylinder to determine how much water was not consumed. Divide that volume by the number of volunteers to determine the average amount of water not consumed, or lost, by each student.
3. Ask the students to multiply the average amount of water lost per student by the number of students in the classroom to figure out how much water would have been lost if they all drank from the fountain.
4. Multiply the answer from step 3 by the total number of classrooms in the school. (Discuss estimating with the students.)
5. Next, multiply that number by the number of days per year that school is in session—usually 180 days.
6. Finally, have the students convert their answer in step 5 to liters to figure out how many liters of water would be lost each school year if every student in the school drank from the fountain for 5 seconds each day. (To help them visualize the amount of water, divide the number by 2 to illustrate the number of 2-liter soda pop bottles that amount of water would fill.)

Challenge the students to explain how this relates to leaving the faucet on when brushing their teeth versus turning the faucet off.

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CONVERTING METRIC UNITS

To work with objects that can vary drastically in size, scientists need to be able to convert between large and small measurements quickly. The SI system makes conversion simple because prefixes are based on groups of ten.

For example, a newborn baby and a large professional football player are placed onto separate balances. One has a mass of 4,000 grams, and the other has a mass of 90 kilograms. Which mass belongs to the football player? Which mass is the baby's? To figure it out, you can convert the measures into the same units:

$$4{,}000\ \cancel{g} \times \frac{0.001\ kg}{1\ \cancel{g}} = 4\ kg$$

From this conversion, we can conclude that the mass of 4,000 g (4 kg) is the baby's mass because it is much smaller than the mass of 90 kg.

QUICK CONVERSION TRICK!

To change from one prefix to another, look at the exponents for those prefixes on page 10.

1. Subtract the exponent for the first prefix from the exponent for the second prefix.
2. Then, move the decimal point that number of places to the right or left, as appropriate. (Move right to go from larger to smaller numbers. Move left to go from smaller to larger numbers.)
3. Finally, fill in with zeros, if necessary.

For example, to change centimeters (10^{-2}) to millimeters (10^{-3}), the difference between the exponents is one. Therefore, you'll move the decimal one place to the right to go from the larger centimeter to the smaller millimeter (1.0 cm = 10.0 mm). Likewise, to change millimeters to centimeters, the difference is still one, but this time you will move the decimal one place to the left to go from the smaller unit to the larger one (1.0 mm = 0.10 cm).

PRACTICE CONVERSION!

Using the background information provided on pages 8–12, introduce students to the process of converting measurements with the activity below.

1. Instruct students to use the average length measurement determined from the previous activity, Practice Measurement!, and convert the length into micrometers, millimeters, meters, and kilometers.
2. Have them do the same for the width and height measurements.
3. Review the correct answers as a class.

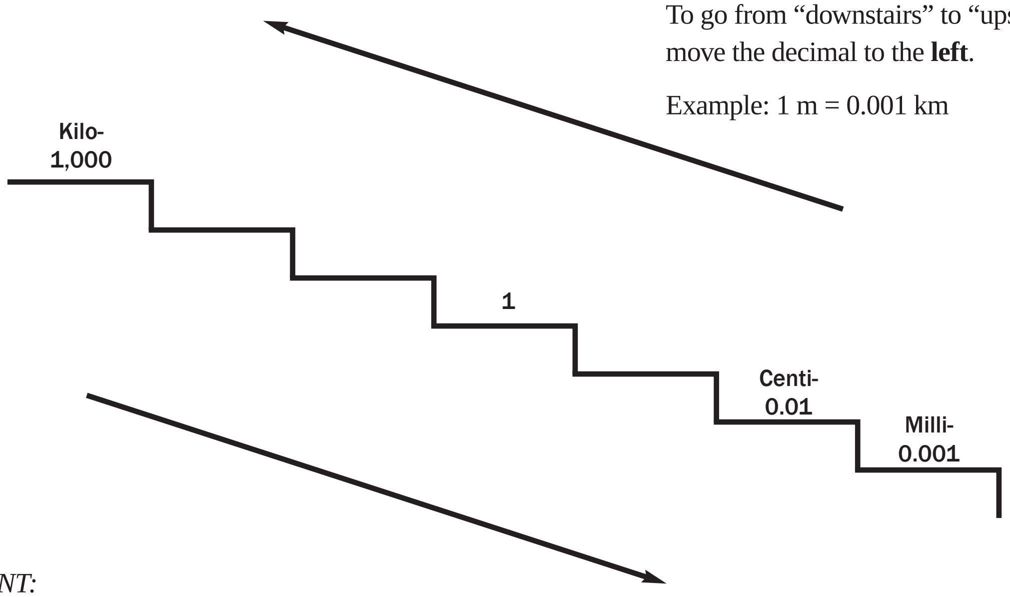
You can also provide students with the following illustration to help them visualize the process as they practice conversion.

METRIC CONVERSIONS "STAIR CHART"

HINT:

To go from "downstairs" to "upstairs," move the decimal to the **left**.

Example: 1 m = 0.001 km



HINT:

To go from "upstairs" to "downstairs," move the decimal to the **right**.

Example: 1 km = 1,000 m