Measurement in Science
Process skills

Why?
Many observations of events in the natural world are best described with numbers, or quantitative data. Measurements allow us to determine and describe properties, patterns and relationships among living and non-living things in the natural world. Making accurate measurements and correctly interpreting the measurements of others allows us to learn more about our world. Such measurements are known as empirical data. Empirical means that the data are based on evidence rather than opinion. In this activity, you will sharpen your skills in measuring length, volume, and mass.

Before you can understand volume measurements, you must understand length and the units used to describe length. Be watchful for the connection between length and volume.

There are 3 basic methods for measuring volume and two methods used to measure mass. You have probably done each method at one time or another. The purpose of this activity is to help you understand how each technique works, when to use each technique, and to use each technique in a manner consistent with other scientists.

Measuring and Understanding Length and Volume
There are 3 basic methods of measuring volume to keep in mind as you work through this lab.
1. Measure and Calculate - used for solids of regular shapes. For a rectangular solid, for example, the length, width, and height are measured and recorded. The volume is then calculated using the equation V = l \times w \times h.
2. Direct measurement - Used to measure the volume of a given liquid. Place the liquid whose volume is to be measured into a graduated cylinder and read the volume directly from the scale on the cylinder.
3. Displacement - Used to measure the volume of an irregularly-shaped solid. Add water (or another liquid) to a graduated cylinder. Read and record the volume. Slide the solid gently into the cylinder. Read and record the new volume. Calculate the volume of the solid as follows:

\[(\text{Volume of water} + \text{solid}) - (\text{volume of water}) = \text{volume of solid}\]

PART 1. Measure and Calculate: Understanding Length and Volume Measurements:
The purpose of this exercise is to help you understand how volume measurements are actually based on length measurements. Read the definition of Measure and Calculate, above.

Materials:
- Bag of 40-50 plastic cubes, assorted colors
- Centimeter ruler

Directions: Work in pairs. Use 2 sets of equipment. Discuss with group of 4.

1. On the ruler, the decimal place that can be read is __________. The decimal place that should be estimated is __________. The ruler is said to be precise to within ________________
2. Place a cube on the table in front of you so that any side of the cube is facing you. The side facing you will be the called the length. The side pointing straight up, perpendicular to the table, will be the height. The remaining side, flat on the table and protruding away from you, will be the width.

3. Using the centimeter ruler, measure and record the length, width, and height in Model 1, Table 1 for 1 cube with precision appropriate to the instrument you are using. Record the measurements in Model 1, Table 1, Length, Width, and Height.

Model 1
Table 1: Cube Dimensions

<table>
<thead>
<tr>
<th></th>
<th>Length (cm)</th>
<th>Width (cm)</th>
<th>Height (cm)</th>
<th>Calculated Volume (cm$^3$)</th>
<th>Volume in mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 cubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 cubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 cubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 cubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Find the volume of the cube using the exact format below. Record the calculated volume in the Calculated Volume column Model 1, Table 1 for 1 cubes.

Calculate the volume in centimeters of 1 cube:
Length (cm) x width (cm) x height (cm) = volume (cm$^3$)


√

5. Place a second cube to the right of the first cube. The sides should touch to form a rectangle.

6. Using the centimeter ruler, measure and record the length, width, and height in Table 1 for 2 cubes with precision appropriate to the instrument you are using.

7. Find the volume of the 2 cubes using the formula below. Calculate the volume of 2 cubes and record the calculated volume in Record your answer in the Calculated Volume column Model 1, Table 1 for 1 cubes.

Calculate the volume in centimeters of 2 cubes:
Length (cm) x width (cm) x height (cm) = volume (cm$^3$)


√

8. Place a third cube to the right of the second cube. The sides should touch to form a rectangle with 3 cubes in a line.
9. Using the centimeter ruler, measure and record the length, width, and height in Table 1 for 3 cubes with precision appropriate to the instrument you are using.

10. Find the volume of the 3 cubes using the formula below. Calculate the volume of 3 cubes and record the calculated volume in the **Calculated Volume column Model 1, Table 1 for 3 cubes**.

   Calculate the volume in centimeters of 3 cubes:
   \[ \text{Length (cm)} \times \text{width (cm)} \times \text{height (cm)} = \text{volume (cm}^3\text{)} \]
   \[ \underline{\text{_______}} \times \underline{\text{_______}} \times \underline{\text{_______}} = \underline{\text{_______}} \]

   A written calculation is an explanation of the process and information used to get an answer. There are 3 parts:
   1. A statement telling what quantity will be calculated.
   2. The equation used to get the needed value
   3. The math in the form of an equation, including the units with each measurement.

   Use this process for each calculation you do in lab from this point forward.

   Go back to steps 4, 7, and 10 above and label the parts of each calculation 1, 2, or 3.

   11. Place 4 more cubes to the right of the third cube. The sides should touch to form a rectangle with 7 cubes in a line.

   12. Using the centimeter ruler, measure and record the length, width, and height in **Calculated Volume column Model 1, Table 1 for 7 cubes**.

   13. Use the 3-step process you just learned to find the volume of the 7-cube. Write the steps below and record your answer in Table 1.
15. Place 3 more cubes to the right of the 7th cube, in a line with sides touching. The cubes should form a 10-cube rectangle. Measure and record length, width, height in Table 1.

16. Using the centimeter ruler, measure and record the length, width, and height in Table 1 for 10 cubes.

17. Use the 3-step process you just learned to find the volume of the 7-cubes. Write the steps below.

18. In the space below, write a description of the process used to write a calculation. Include an example.
Relationship of Length and Volume

A cube measuring 1 cm on each side has a volume of 1 cm³.
1 cm³ is also called 1 mL.

mL is the abbreviation for milliliter, a unit of volume commonly used in science.
The equality statement is written as

\[ 1 \text{ mL} = 1 \text{ cm}^3 \]

Write the volume of each shape in Model 1 in Table 1 in the column Volume in mL.

19. Stack 9 more cubes on top of the first cube. What is the height of the stack of 10 cubes? _________

20. Arrange 9 more cubes so they make another link perpendicular to both the original line of cubes and the stack.

What is the length of this line of cubes? ______________

21. Use the model you built of cubes (how many cubes total are in the model right now? ________) and the unused cubes to estimate the number of 1 cm³ cubes you would need to build a 1000 cm³ cube.

Describe, in words below, how you figured out the number 1 cm³ cubes of needed.

Number of cubes needed: __________

Explanation:

22. If 1 cm³ = 1 milliliter, and milliliter is a measure of volume, what is the volume in mL of the (partial) cube you just built? __________

A volume equal to 1000 mL is known as 1 Liter. The Liter as a unit of measurement is defined by a cube measuring _____ cm on each side.

23. Write an equality statement showing the relationship between milliliters and Liters.

______ mL = _______ L

23. What types of materials is it best to use the measure and calculate method of determining volume: Why?
PART 2: Direct Measurement of Volume: Using a Graduated Cylinder:

Materials: Graduated Cylinders: 10 mL, 25 mL, 100 mL.
          Beaker, 400 or 600 mL, with about 300 mL water

Directions:
Graduated cylinders have numerical scales based on their size. The major lines, or grids, have numbers next to them. The numbers represent milliliters (mL). Between the major grids are smaller lines, or minor grids, that allow you to read the volume more precisely. Work in pairs; discuss in group of 4.

1. Determine the value in mL for the minor grid lines on each cylinder a-d below and d them on the Response Page.

Model 2

2. When reading a graduated cylinder, keep the cylinder on the desk and bring your eyes to line up with the lowest point of the top of the liquid in the cylinder. When reading the measurement, read all the numbers you can know for certain. If the liquid level is between 2 lines, estimate one additional number. Record all the numbers.

   If you think the level of the liquid is exactly on a line, the last (estimated) digit in your measurement will be recorded as a zero. You read the lowest point on the liquid surface.

What is the name for the lowest point on the liquid surface? ________________

By estimating between the minor grid lines, instead of reading “about 20 mL,” you can measure precisely to the nearest 1, 2, or 5 mL and estimate 0.1 mL; ex. 20.0 mL.

As in reading a ruler, you can estimate one decimal place more than the smallest grid line markings on the cylinder. Use these rules:

   If the smallest grid line value is 0.1 mL, estimate between the gridlines to record 0.01 mL
   If the smallest minor grid line is 0.2 mL, estimate the nearest 0.1 mL
3. Find the volume of liquid represented by the meniscus in each drawing in Model 4, below. Write the volume reading below each cylinder, next to the letters. Remember to determine the value of the minor grid lines for each cylinder first.

**Model 4**

![Diagrams of graduated cylinders with meniscus levels]

a) _________  b) _________  c) ________  d) _________

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4. Next, get out graduated cylinders with capacities of 10, 20, 50, and 100 mL.

- Fill the 10 mL cylinder to 10.0 mL. You may use a Beral pipet to do this, knowing you will never measure this way again.
- Fill the 25 mL cylinder to 19.6 mL
- Fill the 100 mL cylinder to 44.4 mL

Everyone in your group should agree that the volume of water added is correct. Pour the water into the sink.

5. Fill each cylinder with a random amount of water. Be sure the miniscus is below the highest marking.

6. Choose a group member to record as Volume 1 in Model 5, Table 2 and write his or her name in the table. Choose another group member for Volume 2, another for Volume 3, and another for Volume 4. Record their names in the table.

7. Each group member should read the volume in each cylinder *individually*, with as much detail as possible, and record your answer. Do not assume anything about the volume. *When everyone is finished, check with your group and record all responses in your table.*
Model 5
Table 2: Cylinder Volumes

<table>
<thead>
<tr>
<th>Group member name -&gt;</th>
<th>Cylinder 10 mL</th>
<th>Volume 1 (mL)</th>
<th>Volume 2 (mL)</th>
<th>Volume 3 (mL)</th>
<th>Volume 4 (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 mL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 mL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


9. Which cylinder allowed you to read the most precise volume? Why?

Part 3: Measuring volume by displacement:

Materials: Graduated Cylinders: 100 mL
7 plastic cubes
Water

Directions:
Use your measuring skill from Part 1 and 2 to obtain measurements needed to find volume by displacement. Work in pairs; discuss in group of 4.

1. Fill a 100 mL graduated cylinder to the 35 mL mark with water. Record the volume in Table 3. Drop in 7 of the plastic cubes. Read and record the volume of the cubes + water together, in Table 3.

Model 6
Table 3 Volume of 7 Cubes by Displacement

<table>
<thead>
<tr>
<th>Substance Measured</th>
<th>Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Water + cubes</td>
<td></td>
</tr>
<tr>
<td>Calculated volume of cubes</td>
<td></td>
</tr>
</tbody>
</table>
2. Calculate the volume of the cubes using the 3-step calculation process you learned in Part 1:

3. Repeat the process for 3 cubes and then for 10 cubes. *Construct labeled data tables and lay out the calculations. Refer to Model 6 above and the calculation there.*

   3 cubes:

   10 cubes:
4. For what kinds of materials would you use the Displacement method to measure volume? Explain.

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Measuring Volume Summary

Re-read Discuss with your group and reach consensus about what substances could be measured with each method. Record your answers below.

<table>
<thead>
<tr>
<th>Method of Measurement</th>
<th>Substance to measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure and Apply Formula</td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td></td>
</tr>
<tr>
<td>Displacement</td>
<td></td>
</tr>
</tbody>
</table>
Using the Balance

When finished with this activity, you will understand how a balance works and use it to measure mass using the following 2 techniques:
1. direct measurement
2. difference

Materials

Triple-beam balance

Directions:
Read and discuss in group of 4

Measuring and Understanding Mass

There are 2 basic methods of measuring mass to keep in mind as you work through this lab.

1. **Direct Measurement** - used for solids of regular shapes. Simply place the solid object on the balance pan, move the sliders until the pointer and scale align, and record the values on the riders.

2. **Difference** - Used to measure the mass of a powder of crystalline solid, or any substance or objects in small pieces. Place a weighing paper or container on the balance, and record the mass. Add the needed amount of substance to be weighed to the paper and record the mass of the substance and paper together. Subtract the mass of the paper to get the mass of the substance needed. Calculate the mass of the solid as follows:

   \[(\text{mass of paper} + \text{substance}) - (\text{mass of paper}) = \text{mass of substance}\]

Model 7

![Diagram of triple-beam balance]

Mass of object is equal to sum of readings. For instance, when masses are in positions indicated by arrows, the mass is 356.6 grams.
Part 4: Operating the Balance

1. Examine the balance at your lab station. Remove the cover and place it aside. Consult Model 7, above, to learn the names of the functional parts of the balance. Locate each part on the balance at your table. Label each on the diagram in Model 7.

- **Platform (pan)**
- **Beams**
- **Riders (sliding masses)**
- **Pointer**
- **Scale**
- **Zero-adjustment knob**
- **Number**
- **Base**
- **Fulcrum**

Always use the same balance throughout an experiment. There are small variations in the balances, and using the same one throughout will introduce a consistent variation that can be neglected.

To be sure you use the same balance, record the number on your data table at the beginning of the lab. Check the balance number with each use.

2. Be sure all of the riders are firmly in place at zero, and that the pan is clean. Wipe the pan with a damp paper towel, if needed.

3. The balance is zeroed if the pointer stops exactly at the scale, or if the pointer is swinging up and down with equal-sized swings up and down.

4. Locate the zero adjustment mass. To correctly zero the balance, you will gently turn this mass either to the right or to the left.

5. Wait for the pan to stop moving and check the position of the pointer. Is it above, below, or right on the zero mark on the scale? __________

6. Now turn the zero adjustment mass 1-1.5 turns toward the back of the balance (you will be moving your thumb upward.) Observe the new position of the pointer. Did turning the mass in this direction raise or lower the pointer? __________

7. If the pointer is above the scale, there is too much mass on the left side of the fulcrum. Adjust this by screwing the zero adjustment mass so that it moves inward. Adjust in small increments, checking the position of the pointer and scale between adjustments until the scale and pointer agree.

8. If the pointer comes to rest below the scale, there is too much mass on the right side of the fulcrum. Adjust this by unscrewing the zero adjustment mass so that it moves outward.

9. When you check the alignment of the pointer and the scale, be sure you are at eye level with the balance, and that you are looking perfectly straight on at the pointer and scale.

Write a statement describing how you can remember which way to turn the zero adjustment knob to zero the balance:

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10. Examine the beams and riders on the right-hand side of the balance and answer these questions:

There are ______ beams. The beam in back is Beam 1, the Beam in the middle is beam 2, and the beam closest to you in Beam 3.

Which beam measures grams? _______

Tens of grams? _______

Hundreds of grams? _______

Tenths of a gram? _______

Hundredths of a gram? _______

Can you measure to the nearest 0.001 gram on this balance? Explain.

Since you can obtain a mass to the nearest 0.1 grams with accuracy and estimate the value in hundredths place, any measurements you make on this type of balance should be recorded to the nearest 0.00 g or the nearest 0.01 gram. Use 2 numbers after the decimal point even if you believe the measurement to be X.00. The tenths scale may be read with certainty, but the hundredths cannot, because there is no calibrated scale to read for hundredths. The digit for hundredths is estimated to the nearest 0.01 gram only. The uncertainty of this balance is +0.01 or -0.01.
Part 4: Measuring Mass by Direct Measurement:

Materials

- Triple-beam balance
- 10 cubes

Directions:
Work and discuss in group of 4. Rotate the handling of the balance among group members. Be sure each person practices reading the balance and understands the masses recorded.

In Part 4, you will correctly obtain the mass of 3 cubes, then 7 cubes, then 10 cubes. Record the masses in numbers and units in Data Table 4.

1. Be sure the scale is zeroed and all the riders are set to zero.
2. Place 1 cube on the balance pan.
3. Record the mass to the nearest hundredth of a gram in Model 8, Data Table 4.
4. Repeat for 3, 7, and 10 cubes.

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Part 4: Measuring Mass by Difference:

Practical Uses and Applications:
Since you cannot place a liquid directly on the balance pan, you will need to develop a technique for obtaining the mass of a small amount a liquid or solution. The next few exercises will allow you to design a procedure for doing so. You will also learn to use a data table for recording this information and displaying it in a lab report.

Materials:

- Balance
- 1 small beaker (50 or 100 mL)
- 25 mL graduated cylinder
- Approximately 20 mL water
- Small cup of sand
- Empty cup

Mass of a Liquid - measurement by difference
Use the techniques you just learned to obtain the mass of one of the small beakers with the most precision possible (use 3 decimal places, the last one, which is an estimate, being either 0 or 5).

1. Zero the balance, place the beaker on the balance, and obtain the mass. Record the mass in Model 8, Table 4.

2. Next measure about 20 mL of water in your graduated cylinder, and add it to the beaker you just massed. Obtain the mass of the beaker and the water together. Record the mass in Model 8, Table 4.
3. To find the mass of the water only, you must do a calculation. Subtract the mass of the empty beaker from the mass of the beaker with the water. Write the 3-step calculation in the space below. Record your answer in Model 9 Table 5 Calculations Table

No matter how simple or obvious a calculation seems to you, a reader might be confused if you don’t include this explanation of how you got these numbers. It’s also helpful to you should you need to re-trace your steps for any reason.

Mass of Dry Chemicals - measurement by difference

Practical Uses and Applications:
Since you cannot place a chemical directly on the balance pan, you will need to develop a technique for obtaining the mass of a small amount of powdered or crystalline chemical. The next few exercises will allow you to learn a procedure for doing so. You will also learn to use a data table for recording this information and displaying it in a lab report

Your task is to weigh about 3 grams of sand, to the most precision possible on your balance.

Materials
  Balance
  1 small beaker (50, 100, or 150 mL will do)
  scoopula
  several scoopfuls of sand (Place this in your beaker and return it to the sand buckets when you finish.)
  1 square of weighing paper

1. Zero the balance. Fold the weighing paper in half and then in half again to make a “dish.”
2. Place the weighing paper on the balance pan and obtain its mass. Record the mass of the paper in Model 8, Table 4.
3. To mass out approximately 3 grams of sand:
   - Set the riders on the balance to the mass of the weighing paper plus 3 grams.
     (Ex. mass of weighing paper was 1.17 grams, add 3 grams to get 4.17 grams.)
   - Place the weighing paper on the balance pan. Use the scoopula to add small portions of sand to
     the paper.
     See demo and instructor for technique.
   - When the pointer is close (within a few mm) to being zeroed in on the scale, stop adding sand. If
     you go too far past zero and have added too much sand, use the scoopula to remove some.
   - PRO TIP: It’s faster to remove too much and have to add it again than it is to remove several
     small amounts.

4. Now, adjust the riders on the beams to show the exact mass of sand. It will not be exactly 3 grams,
   but it will be close.

   NOTE: It’s very difficult to add an exact amount of material to the balance pan, so using an
   amount close to the specified amount is perfectly OK as long as you measure and record exactly
   how much you really do have.

5. Read the exact mass from the beams and record in **Model 8 Table 4**.

6. Next With your group, devise and follow a calculation to find the mass of the sand only, not including
   the paper. Write your 3-step calculation in the space below and record your answer in **Model 9 Table 5**.
Model 8
Data Table 4: Masses

<table>
<thead>
<tr>
<th>Substance</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of 1 cube</td>
<td></td>
</tr>
<tr>
<td>Mass of 3 cubes</td>
<td></td>
</tr>
<tr>
<td>Mass of 7 cubes</td>
<td></td>
</tr>
<tr>
<td>Mass of 10 cubes</td>
<td></td>
</tr>
<tr>
<td>Mass of empty beaker</td>
<td></td>
</tr>
<tr>
<td>Mass beaker + 20 mL water</td>
<td></td>
</tr>
<tr>
<td>Mass weighing paper</td>
<td></td>
</tr>
<tr>
<td>Mass weighing paper + sand</td>
<td></td>
</tr>
</tbody>
</table>

Model 9 Table 5 Calculations Table

<table>
<thead>
<tr>
<th></th>
<th>grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass of water</td>
<td></td>
</tr>
<tr>
<td>mass of sand</td>
<td></td>
</tr>
</tbody>
</table>

Analysis
1. List the 3 steps needed to correctly communicate any calculation.

2. Describe the difference between a data table and a calculations table. What does each contain?

3. Make a Google doc that describes 3 ways to measure volume and 2 ways to measure mass. Include sample data and calculations where needed.