When people do scientific experiments, they try to shed light on the unknown or figure out how the world works. How do scientists know where to start? Well, they ask questions.

In order to get answers, scientists start with a puzzling question. Scientists have tried to answer the following:

- How do birds know where to migrate?
- How can we predict earthquakes?
- Is there life elsewhere in our solar system or in the universe?
- Do elephants use sound to communicate?

Then they try to answer their question by making an educated guess. The following are guesses to answer the first question:

- Birds tell direction by watching the sun rise and set.
- Birds have a built-in “road map” to follow.
- Birds can tell direction by sensing the Earth’s magnetic field.
- Birds remember their course by spotting familiar landmarks.

These four sentences are examples of hypotheses. A hypothesis is an educated guess or possible answer to a question. Scientists test their hypothesis by doing an experiment. The following is an example:

**Question:** How do birds know where to migrate?

**Hypothesis:** Birds are directed by the Earth’s magnetic field.

**Experiment:** Create an electric circuit that produces a magnetic field. Attach this circuit to a bird so that the bird’s ability to *sense the Earth’s magnetic field*—if such an ability exists—is disrupted. If the bird can still migrate normally, then the hypothesis is probably wrong.

**Identifying a Good Hypothesis**

Not all hypotheses are useful. Consider the following hypothesis:

**Hypothesis:** Birds are guided by the spirits of dead antelopes.

Could you design an experiment to test such a hypothesis? Even if you could find spirits of dead antelopes, they would probably be hard to control in an experiment. The point is that a good hypothesis is one that can be tested.
Evaluate each hypotheses based on whether it can be tested, and place an X in the appropriate column.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Can be tested</th>
<th>Cannot be tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>If the polar ice caps begin to melt, the amount of salt in ocean water will change.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dogs use mind control on their owners to be taken for walks and car rides.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If an animal is deaf, then it cannot hear.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A propeller with large blades can propel an airplane faster than a propeller with smaller blades can.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**More on Hypotheses**

Hypotheses help explain puzzling situations or events. Hypotheses answer “how,” “what,” and “why” questions. Explain each of the following situations with a hypothesis:

1. You hang a bird feeder, fill it with food, but no birds come to it.
   
   **Hypothesis:**
   
   __________________________________________________________________________
   
   __________________________________________________________________________

2. In your new house, you see fewer stars from your bedroom window. You’re looking at the same place in the sky.
   
   **Hypothesis:**
   
   __________________________________________________________________________
   
   __________________________________________________________________________

3. After you put a plastic food container in the dishwasher, its lid no longer fits correctly.
   
   **Hypothesis:**
   
   __________________________________________________________________________
   
   __________________________________________________________________________

**TROUBLESHOOTING**

Create a two-column table. Label one column “Cause” and the other “Effect.” Put a puzzling situation or event in the “Effect” column. Think of some causes, and list them in the “Cause” column. Every cause you write is actually a hypothesis!

**TRY THIS!**

You’ve probably heard that you can prove a hypothesis wrong but that you can’t prove it right. Explain why this is true.
Designing an Experiment

The following report was written by a middle-school science student:

My question was, “Why do some helium balloons last longer than others?” I did research and discovered that balloons aren’t filled with pure helium. My hypothesis was that balloons with a higher percentage of helium last longer.

In my experiment, I filled 12 balloons with helium. Four of them were completely filled to 30 cm across. Four were filled to 20 cm across. Four were filled to about 10 cm across. The balloons lasted about the same amount of time, so my hypothesis was not true.

On the report evaluation, the teacher wrote, “Good idea, but you didn’t test your hypothesis.” What do you think the teacher meant?

__________________________________________________________

__________________________________________________________

How could the experiment be changed to test the hypothesis?

__________________________________________________________

__________________________________________________________

Be Sure to Answer the Question

An experiment should test a specific hypothesis. Always ask yourself, “Does my experiment match my hypothesis?”

For example, Makiko wanted to test the following hypothesis: “Gerbils can think better right after they eat.” She built a maze to test her eight gerbils’ thinking ability. At first, she planned to test four gerbils right after they had eaten one brand of gerbil food and the other four after they had eaten another brand of gerbil food. Would this experiment test Makiko’s hypothesis? Write the hypothesis you think this experiment would test.

Makiko decided she would feed her gerbils at 8 P.M. every evening. Then she would test four gerbils in the maze at 8:30 P.M. and the other four on the following morning. This experiment would test her original hypothesis.
**Asking the Question**

What hypothesis is each of the following experiments designed to test? For each experiment, provide an appropriate hypothesis.

1. Makiko fed half her gerbils all at once. The other half were fed their daily ration in three equal parts—in the morning, at midday, and at night. After a month, all of the gerbils were tested in the maze.

   **Hypothesis:**

2. Makiko kept half her gerbils in a cage on a table surrounded by plants. She kept the other half in a cage on a table without plants. After a week, she tested the gerbils in the maze.

   **Hypothesis:**

**A Bit More Practice**

For the following puzzling event, propose both a hypothesis and an experiment that tests your hypothesis.

3. You return to the car from an all-day shopping spree at the mall. Your favorite CD, which you left on the dashboard, is now stuck.

   **Hypothesis:**

   **Experiment:**

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**Troubleshooting**

Write down the different variables that your hypothesis mentions. Your experiment to test your hypothesis should use the same variables. Present your hypothesis to your class, and explain your experiment.

**Try This!**

Why is it important for Makiko to use more than one gerbil in each of the experimental trials? For instance, in one experiment she fed four gerbils once a day and four gerbils three times a day. Why didn’t she just use two gerbils, one for each feeding schedule?
EXPERIMENTING SKILLS

Using the International System of Units (SI)

In the United States, few people besides scientists use the International System of Units (known as SI for Système International d’Unités) regularly. SI is becoming more common for two reasons.

• Once you learn and practice SI, it is easier to use than the standard English system.
• As communication systems and businesses become increasingly global, there is a growing need for a worldwide standard measurement system.

These are reasons why students are required to learn SI in school. We already use SI for many things. For instance, most beverages are sold in 2 L or 3 L bottles. What other items are measured with SI units?

Match 'Em Up!
Match the SI unit with the dimension that it measures:

1. _____ meter
   a. volume
2. _____ gram
   b. area
3. _____ liter
   c. mass
4. _____ square kilometer
   d. length

Match the SI prefix with its meaning:

5. _____ nano-
   e. one-tenth
6. _____ centi-
   f. one thousand
7. _____ micro-
   g. one-thousandth
8. _____ kilo-
   h. one-millionth
9. _____ deci-
   i. one-billionth
10. _____ milli-
    j. one-hundredth

Remember
As you read, watch for words such as nanosecond, kilocalorie, milliliter, and micrometer.
Using the International System (SI), continued

**Conversions**

Convert between SI and English units with the following factors:

<table>
<thead>
<tr>
<th>Mass</th>
<th>Volume</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lb</td>
<td>454 g</td>
<td>1 ft</td>
</tr>
<tr>
<td>1 g</td>
<td>0.0022 lb</td>
<td>0.305 m</td>
</tr>
<tr>
<td>1 gal</td>
<td>3.78 L</td>
<td>1 m</td>
</tr>
<tr>
<td>1 L</td>
<td>0.26 gal</td>
<td>3.28 ft</td>
</tr>
</tbody>
</table>

There is a handy method of doing conversions based on this figure:

Here’s an example: How many centimeters is 38 ft?

**Step 1:** Put the known quantity in the upper-left space, as follows:

<table>
<thead>
<tr>
<th>38 ft</th>
</tr>
</thead>
</table>

**Step 2:** Put a conversion factor (also called an equality) in the next set of boxes to the right. Make sure that the units match diagonally. We started with feet on top, so we’ll put feet on the bottom when we fill in the conversion factor, as follows:

<table>
<thead>
<tr>
<th>38 ft</th>
<th>0.305 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ft</td>
</tr>
</tbody>
</table>

Note: There are two conversion factors listed above for feet and meters. You can use either one as long as you put feet on the bottom.

**Step 3:** Cross out, or cancel, the units that appear on both the top and the bottom, as follows:

<table>
<thead>
<tr>
<th>38 ft</th>
<th>0.305 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ft</td>
</tr>
</tbody>
</table>

**Step 4:** Now ask, “Is the unit that’s not crossed out the one I want?”

- If the answer is yes, then continue to Step 5.
- If the answer is no, return to Step 2.

For our example, the unit that’s left is meters. We’re looking for centimeters, so we’ll return to Step 2.

**Step 2:** Remember to match units diagonally.

<table>
<thead>
<tr>
<th>38 ft</th>
<th>0.305 m</th>
<th>100 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ft</td>
<td>1 m</td>
</tr>
</tbody>
</table>
EXPERIMENTING SKILLS

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Using the International System (SI), continued

Step 3: Cross out the matching units.

<table>
<thead>
<tr>
<th>38 ft</th>
<th>0.305 m</th>
<th>100 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ft</td>
<td>1 cm</td>
<td></td>
</tr>
</tbody>
</table>

Step 4: Is the unit that’s not crossed out the one I want? Yes, we’ve got centimeters, so we’re ready to solve the problem.

Step 5: To solve the problem, multiply the numbers on the top row:

\[38 \times 0.305 \times 100 = 1,159\]

Then multiply all of the numbers on the bottom row:

\[1 \times 1 = 1\]

Now, divide the top row’s product by the bottom row’s product:

\[1,159 \div 1 = 1,159\]

The answer is 1,159 cm!

Your Turn

The following problems will help you practice your metric-to-metric, English-to-SI, and SI-to-English conversions. Be sure to show your work.

1. How many meters is 1,602 ft?

2. How many pounds is 12 g?

3. How many gallons is 0.2 L?

4. How many deciliters is 5 L? (Hint: How many deciliters are in 1 L?)

5. How many meters is 63.9 cm?
**EXPERIMENTING SKILLS**

**Measuring**

Try this puzzle. Suppose that you are given a bottle of water and three beakers. One of the beakers holds 30 mL, one holds 40 mL, and the largest of the three beakers holds 200 mL when full. There aren’t any markings on any of the beakers. Describe how you could put exactly 20 mL of water in the large beaker without using any other equipment.

**Tools of the Trade**

You probably already know that beakers are used for measuring liquid volume. We say that the **dimension of measurement** for a beaker is volume. Examine the following chart, and fill in the empty boxes.

<table>
<thead>
<tr>
<th>Measurement device</th>
<th>Dimension of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>beaker</td>
<td>volume</td>
</tr>
<tr>
<td>stopwatch</td>
<td></td>
</tr>
<tr>
<td>beam balance</td>
<td></td>
</tr>
<tr>
<td>graduated cylinder</td>
<td>distance or length</td>
</tr>
<tr>
<td></td>
<td>temperature</td>
</tr>
</tbody>
</table>

Precise measurements and accurate readings are very important aspects of scientific experimentation.

Here are some pointers for accurately measuring the volume of a liquid:

- Place the container on a flat surface.
- Make sure the container is at eye level when you read the volume.
- If you have trouble seeing the level, hold a blank piece of paper behind the container while you read the volume of the liquid.
In a graduated cylinder or beaker, most liquids form a **meniscus**, or a curved upper surface. A meniscus is caused by surface tension. When a liquid, such as water, is more attracted to the walls of the container than to itself, it curves up at the edges like a smile. When some liquids, such as mercury, are more attracted to themselves than to the walls of the container, they curve down like a frown.

**When you read the volume of a liquid, read it from the center of its meniscus, not from the curved edges.**

For practice, read the volume of the following liquids. Each longer graduation represents one milliliter.

1. Volume: __________  
2. Volume: __________
Uncertainty in Measurement
Anne brought a 1 L bottle of vinegar from home to use in an experiment on volcanoes in science class. She poured the contents of the bottle into a large beaker and carefully measured it. She was surprised to find that the vinegar's measured volume was actually 1.02 L. Anne thought the bottle contained exactly 1 L of vinegar. What possible explanations can you think of for the difference?

Accuracy in Measurement
No measurement is 100 percent accurate. All measurements have some degree of uncertainty. When taking measurements, you should always ask yourself, “How accurate is this measurement?”

For a measurement to be of any worth, it must have something that indicates its reliability. A measurement's accuracy is expressed as its potential amount of error. For instance, the smallest unit of measurement on a metric ruler is usually a millimeter. The most accurate measurement you could possibly make with that ruler is to the nearest millimeter; thus, the measurement's accuracy is ± 0.5 mm.

This is important because not all measurements have the same accuracy. The total accuracy of your work is only as reliable as your least accurate measurement. Following is an example:

Ricardo added the following three liquids to a beaker:
- 7.9 mL of liquid A
- 2.1 mL of liquid B
- 250 mL of liquid C
Ricardo measured liquids $A$ and $B$ with a narrow graduated cylinder that had markings for every 0.1 mL. He measured liquid $C$ in a beaker that had markings only for every 10 mL. Thus, the volume of liquid $C$ was only accurate to within about 5 mL.

As a result, Ricardo correctly stated that the total volume of the mixture in the beaker was $(7.9 + 2.1 + 250) \text{ mL} = 260 \text{ mL} \pm 5 \text{ mL}$.

**Matchmaker**

Match the measurement devices below with their level of accuracy.

1. _____ metric ruler with markings as small as millimeters
2. _____ graduated cylinder with markings as small as 2 mL
3. _____ scale with markings as small as 0.01 g
4. _____ thermometer with markings as small as 1°C

   a. about 0.5 g
   b. about 1 mL
   c. about 0.5°C
   d. about 1 mm
   e. about 0.5 mm
   f. about 0.005 g
   g. about 0.1°C

**Troubleshooting**

Think of accuracy in terms of money. When someone says, “That costs about $20,” which of the following would you think is most accurate: (a) the price is correct, give or take $10; (b) the price is correct, give or take $1; or (c) the price is correct, give or take 1 cent? The most accurate estimate is probably (b).

**Try This!**

The next time your family buys gasoline, pay attention to how accurately the gas pump tracks the volume of gas—very accurately! For contrast, notice how accurately the car’s gas gauge measures the amount of gas in the gas tank—not very accurately!