KEY CONCEPT

1.2 Science depends on accurate observations and measurements.

Sunshine State STANDARDS

SC.H.1.3.2: The student knows that the study of the events that led scientists to discoveries can provide information about the inquiry process and its effects.

SC.H.1.3.5: The student knows that a change in one or more variables may alter the outcome of an investigation.

BEFORE, you learned

- Science is a way to explore the natural world
- Scientific ideas are tested
- Science is based on objective observations

NOW, you will learn

- How measurements are used in comparisons
- How to identify variables
- Why measurements might be repeated many times

FCAT VOCABULARY

variable p. 16
independent variable p. 16
dependent variable p. 16

VOCABULARY

International System (SI) p. 16
controlled variable p. 17
trial p. 18

EXPLORE Warmth

How do you measure warmth?

PROCEDURE

1. Wrap your right hand around the warmest bottle and your left hand around the coldest bottle. Slowly count to five, then release the bottles.
2. Close your eyes while your partner moves all three bottles and places one in front of you.
3. Touch the bottle with your right hand. Describe its temperature. Repeat with your left hand. Then put both hands on the bottle and describe its temperature.

MATERIALS

3 bottles of water at different temperatures

WHAT DO YOU THINK?

How did your description of the bottle's temperature change during step 3?

Scientists observe with their senses.

In everyday life, *observing* usually means sitting still to watch and listen. In science, though, observing can be very active. You may move or change what you're observing. You make decisions continually. You might decide how to examine an object, what behaviors to pay attention to, and whether to touch or smell something in an experiment. You evaluate the possible risks and take precautions, such as wafting gases toward your nose rather than smelling them directly. Usually you should not taste things because it is too risky.

REMINDER

You can read more about observing and safety beginning on page R2.

Tools and instruments can help you make observations. You might use a stick to pry up a rock or use a hand lens to see details of a feather. Tools and instruments help you make measurements or observe things that you cannot detect with your senses alone.

CHECK YOUR READING What does scientific observation include?

Measurements help scientists compare information.

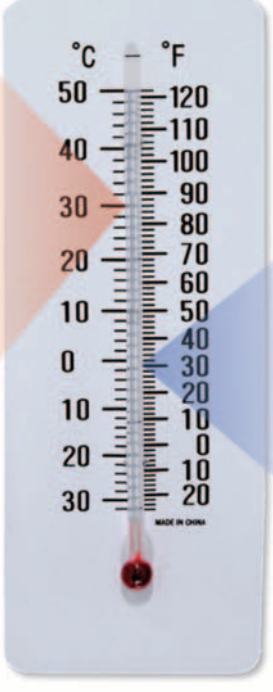
Have you ever thought that the weather was warm but then heard someone else say that it was cold? Both of you were describing information—data—from your senses. However, if you both looked at a thermometer, you might have agreed on the temperature. Descriptions, such as warm or cold, are called qualitative information because they do not include numbers. Information that includes numbers, such as a temperature measurement on a thermometer, is quantitative.

A measurement is quantitative because it includes a number. However, a number alone is not a measurement. A measurement must also include a unit. For example, temperature can be measured using several scales. Some thermometers show the temperature in units of degrees Fahrenheit, or °F. Other thermometers show units of degrees Celsius, or °C. Some show both units. You can see below that 30°C is very different from 30°F. Units are important parts of data.

READING TIP

The words *qualitative* and *quantitative* are related to the words *quality*, a characteristic, and *quantity*, a specific amount or number.

Units of Temperature



A number without a unit is an incomplete measurement. You would choose very different clothes for days with temperatures of 30°C and 30°F.

READING VISUALS How do the photographs and the thermometer show the same thing?

RESOURCE CENTER
CLASSZONE.COM
Learn more about units of measurement.

VOCABULARY
Make a magnet word diagram for International System. See pages R20–R21 for more details about units.

You can make a measurement using any unit, such as the length of your foot or the mass of a coin. However, in science classes you will use standard units, such as meters and grams. Standard units are useful because they make it easy to compare measurements made with different tools. Standard units make it possible to compare measurements made by people in different locations and measurements made by people years or even centuries apart. Scientists use the **International System (SI)** of units, a system of measuring that includes meters, liters, and kilograms. Most smaller and larger SI units differ by factors of 1000. Unit conversions can be made easily by moving the decimal point.

Scientists look for factors that can change.

Scientists make different types of observations and measurements. They may design experiments, collect and examine samples, or observe in the field without trying to affect what they observe. In all types of inquiry, scientists try to identify each possible **variable,** or factor that can change. A factor that does not or cannot change, such as the pull of gravity, is called a constant.

Identifying Variables

There are different types of variables in any inquiry. Some are factors you can make decisions about. You can decide how far to bend a ruler in an experiment, or decide which types of birds to observe at a feeder. The amount of bend in the ruler and the types of birds you choose to observe are possible variables. Because you can change these variables separately, or independently, they are called **independent variables.**

The types of birds you choose to observe at a bird feeder represent one possible variable.

Some factors change as a result of other factors. For example, the number of birds visiting a feeder may depend on the food, the weather, and the type of bird. Factors that depend on other factors are called **dependent variables.** In a scientific inquiry, you often test whether or how an independent variable affects a dependent variable.

To improve your skill at the coin game on pages 12–13, you could study how best to propel the coin, or move it forward. You might try bending the ruler by different amounts and then observe how far the coin moves each time. The amount of bending and the distance the coin moves are variables. Which is the dependent variable?

CHECK YOUR READING What is the difference between an independent variable and a dependent variable?

Controlling Variables

While practicing for the coin game, you might bend the ruler different amounts or hold the ruler at different angles. Each of these can be an independent variable. But if you change both the angle and the amount of bending in the same test, how will you know which affected the coin the most? To avoid such confusion, scientists try to change just one independent variable at a time. Then they can be more confident that the results are linked to the change in that variable. In the same experiment, scientists control—prevent from varying—other possible independent variables. A **controlled variable** is a variable that you choose to keep the same during a particular experiment. You would use a second experiment to test the effect of a second independent variable.

While playing the coin game, you don't want anyone to have an unfair advantage. You try to make the conditions exactly the same for everyone by controlling all the variables you can. For example, everyone could use the same type of coin as well as the same starting line, target, and ruler. In an experiment, too, you identify and control as many variables as you can.

REMINDER

You can read more about variables on pages R30–R35.

INVESTIGATE Variables

How far should you bend a ruler to propel a coin 20 cm?

SKILL FOCUS
Controlling variables

MATERIALS
- tape
- large sheet of paper
- flexible plastic ruler
- coin

TIME
30 minutes

PROCEDURE

1. Follow the instructions for steps 1 and 2 of the coin game on page 12. You will be testing how the amount you bend the ruler affects coin distance. Your goal is to find the value that makes the coin travel a distance of 20 centimeters.
2. Mark a starting position for the coin and the unbent ruler, as shown in the photograph. The ruler should just touch the coin.
3. Mark lines to measure the amount you will bend back the ruler before releasing it, as shown in the photograph. Number the lines for reference.
4. Flick the coin by bending the ruler to different lines. Make at least three trials at each value that you choose. Measure the distance the coin travels from the starting line each time.

WHAT DO YOU THINK?

- Identify the independent variable, the dependent variable, and the constants.
- How well were you able to determine the right amount to bend the ruler?

CHALLENGE What other factors were involved that you couldn't control?

Uncontrolled Variables

You can often design a laboratory experiment so that you either control or change each of the important variables. In other types of inquiries, you may have only a limited ability to control the variables.

For example, weather can affect the way birds feed. You can observe the weather carefully, but you cannot make it exactly the same every day. You can try to make weather an independent variable by making many observations in different types of weather. You can try to make weather a controlled variable by making observations only in one type of weather. You can make important decisions, but your ability to control some variables is limited.

Scientists have a method for reducing the effects of uncontrollable variables. Think about the coin game. To determine the more skilled player, you and your partner could each flick the coin once and compare the results. What problems can you find with this procedure?

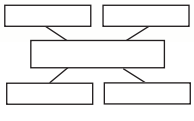
Random chance might affect a single result. Someone might be lucky or unlucky. However, if you play several times, you are more likely to be able to identify the more skilled player. Scientists often repeat a procedure and average the results. Each repetition is called a **trial.** An uncontrolled variable may be different in each trial. When scientists average the results of many trials, the final results depend less on the particular conditions of each separate trial.

Scientists also repeat their observations under different conditions. Suppose scientists are interested in the typical height of waves at a beach. They would measure many different waves. They would also repeat their observations on different days to average out the effects of different weather conditions.

To find a typical wave height, scientists observe many waves and also observe waves on different days.

CHECK YOUR READING Why do scientists make several measurements or trials of the same thing?

MAIN IDEA WEB
Start a new diagram for each blue heading, or main idea.



Scientists evaluate their results.

You have just read that scientists average their results to reduce the effects of uncontrolled variables. They also look at the variations in their results. Two of the factors that scientists evaluate are precision and accuracy.

Precision

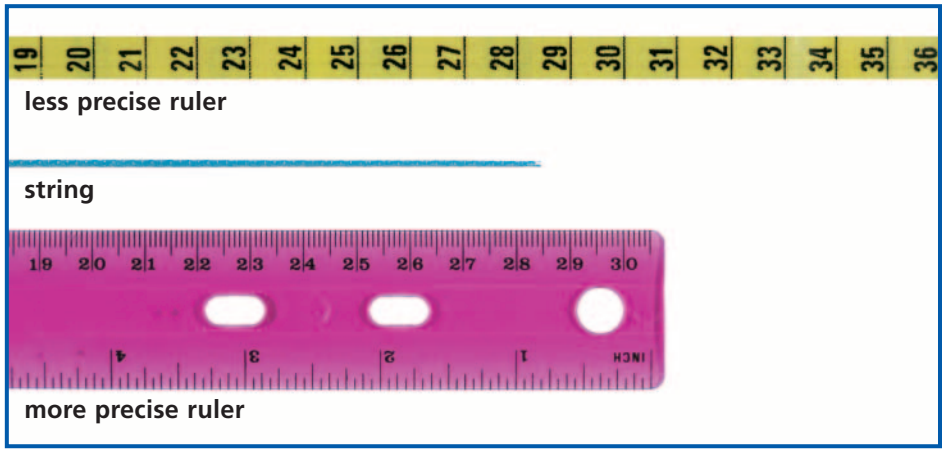
The range of values or possible values gives a scientist important information, called precision. Suppose you estimate a string to be about 30 centimeters long. Then you use a ruler marked in centimeters

to measure the string. You can estimate halfway between the marked divisions. Your result is 28.5 centimeters. A friend, who used a ruler marked in tenths of a centimeter, measured the same string to be 28.65 centimeters. Did you each get the same result?

Both measurements are consistent with your first estimate of 30 centimeters. In your estimate, you used a round number because you meant only that the string was longer than 20 centimeters and shorter than 40 centimeters. The range of possible values is 20–40 centimeters. Both measurements fall within this wide range.

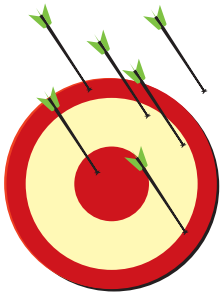
By using the ruler, you were able to narrow the range of possible values. You measured the string's length to the nearest half centimeter. If the string were 0.5 centimeter shorter or longer, you would be able to tell. You determined that the string is 28.0–29.0 centimeters long. Your measurement agrees with your estimate but is more precise. A more precise measurement has a smaller range of possible values.

Your friend's measurement falls within the range you measured, 28.0–29.0 centimeters. Your friend's measurement may look different from yours, but the two agree. However, your friend was able to measure the string to the nearest 0.05 centimeter. The possible range of values is 28.60–28.70 centimeters. Your friend's measurement is more precise than yours.



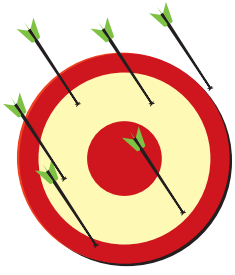
The instruments you used had different precisions. A ruler that is marked in tenths of a centimeter lets you make more precise measurements than one marked only every centimeter. The more finely marked ruler is considered more precise.

Observations can also have different precisions. If a set of trials gives results that are close together—if the range is small—then the results are precise. The results can be physically close, such as a cluster of arrows in a target. Or the results can be close in number, such as similar wave heights or similar numbers of birds visiting a feeder on different days.



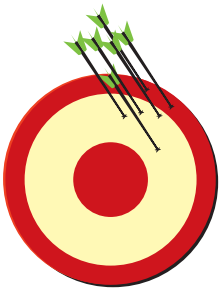
Low accuracy: The cluster of arrows is on one side of the target.

Low precision: The arrows are spread apart.



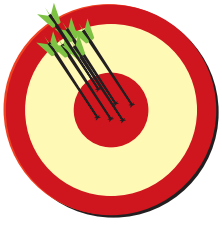
High accuracy: The center of the cluster is close to the center of the target.

Low precision: The arrows are spread apart.



Low accuracy: The cluster of arrows is on one side of the target.

High precision: The arrows are clustered together.



High accuracy: The cluster of arrows is centered on the target.

High precision: The arrows are clustered together.

Accuracy

Results can be very precise but still be wrong. Scientists look for accuracy as well as precision in their measurements. Accuracy compares a measurement with the actual value. If a measurement is accurate, then the true value falls within the range of the measurement.

You measured the string's length to be 28.0–29.0 centimeters. Your friend measured it to be 28.60–28.70 centimeters. The string is actually 28.45 centimeters, which does not fall within the range of your friend's measurement. Your measurement was accurate. Your friend's measurement, although more precise, was not accurate.

Instruments also have accuracy. An accurate instrument gives correct results. An inaccurate instrument, such as a warped ruler, gives incorrect results. The results can have high precision—be very specific—but still differ from the true value. Scientists check their instruments by measuring things they already know. If the measured value differs from the known value, the instrument is not accurate. Some instruments can be adjusted to improve their accuracy.

You can talk about the accuracy of observations too. If trials cluster around the actual value, the results are accurate. Enough trials will produce an average that is very close to the true value. If your friend measured the string several more times, the average of those results might be more accurate than the single measurement.

Accuracy and precision are different but related ideas. Precision describes the range of possible values or the spread of a set of values. If you shoot arrows at a target, good precision means all your arrows land close together—even if they all miss the target. Accuracy compares the center, or average value, with the true value. Accurate archery means the center of your arrow cluster is near the center of the target, even if your arrows are spread over the target.

CHECK YOUR READING How can a measurement be very precise but not accurate?

Evaluating Results

Accuracy is easy to determine when you know the correct answer. But scientists usually ask questions to which the answers are unknown. How can scientists know when they have an accurate result? Three of the techniques scientists use are checking units, making estimates, and checking for consistency.

Checking Units The units of a quantitative result should make sense. If someone's score in the coin game is 10 seconds, you know that something is wrong. The score is determined by length, so units such as centimeters or inches would be appropriate. Units are most likely to get confused during calculations that involve several different units.

Suppose a plant grows 4 centimeters in a week, and you want to know its average growth per hour. You would need to use the formula for rate correctly. You would also need to convert the time correctly from weeks to hours.

Using Estimates Scientists often use round numbers to make rough estimates. They use the estimates to see if their measured and calculated results are reasonable. You might estimate that you can jump up half a meter. If you measure the height you jump to be 3 meters, you should question the result. If you have a result that agrees with an estimate, then your data and calculations are more likely to be accurate.

Checking for Consistency Scientists may make several trials or measurements, or they may try to get the same result in different ways. If the results are similar, scientists are more likely to accept them as valid or trustworthy. Suppose you and your partner measure similar distances for a particular trial of the coin game. You probably accept the result. If your measurements are very different from each other, then you have reason to doubt both measurements. You will need to resolve the difference by checking the way each of you measured or perhaps by measuring again.

Scientists use multiple trials to check for consistency, to estimate precision, and to average out the effects of uncontrolled variables. They repeat whole experiments and also try to get the same results in different ways. They check their measurements, calculations, and conclusions whenever they can.

When an earthquake occurs, the vibrations are detected by seismographs at different locations. These multiple measurements confirm the detection of an earthquake.

CHECK YOUR READING How do scientists check their results? Answer the question in the form of a list.

1.2 Review

KEY CONCEPTS

1. What is the purpose of measurements?
2. Why is it important to identify as many variables as possible in an experiment?
3. Why do scientists repeat the same measurement several times?

CRITICAL THINKING

4. **Sequence** Order these steps as scientists would likely do them: conduct trials, draw conclusions, evaluate data, identify variables.
5. **Infer** What allows a scientist to compare the size of a butterfly today with a description of a butterfly recorded by someone 200 years ago?

CHALLENGE

6. **Apply** Design a simple experiment to test how high a tennis ball bounces. Identify the independent variable, the dependent variable, and variables to be controlled.