SECTION 2

Scientific Methods

READING WARM-UP

Objectives

- Explain why scientists use scientific methods.
- Determine the appropriate design of a controlled experiment.
- Use information in tables and graphs to analyze experimental results.
- Explain how scientific knowledge can change.

Terms to Learn

scientific methods
hypothesis
controlled experiment
variable

READING STRATEGY

Reading Organizer As you read this section, make a flowchart of the possible steps in scientific methods.

Imagine that your class is on a field trip to a wildlife refuge. You discover several deformed frogs. You wonder what could be causing the frogs' deformities.

A group of students from Le Sueur, Minnesota, actually made this discovery! By making observations and asking questions about the observations, the students used scientific methods.

What Are Scientific Methods?

When scientists observe the natural world, they often think of a question or problem. But scientists don't just guess at answers. They use scientific methods. **Scientific methods** are the ways in which scientists follow steps to answer questions and solve problems. The steps used for all investigations are the same. But the order in which the steps are followed may vary, as shown in **Figure 1.** Scientists may use all of the steps or just some of the steps during an investigation. They may even repeat some of the steps. The order depends on what works best to answer the question. No matter where scientists work or what questions they try to answer, all scientists have two things in common. They are curious about the natural world, and they use similar methods to investigate it.

Reading Check What are scientific methods? *(See the Appendix for answers to Reading Checks.)*

scientific methods a series of steps followed to solve problems

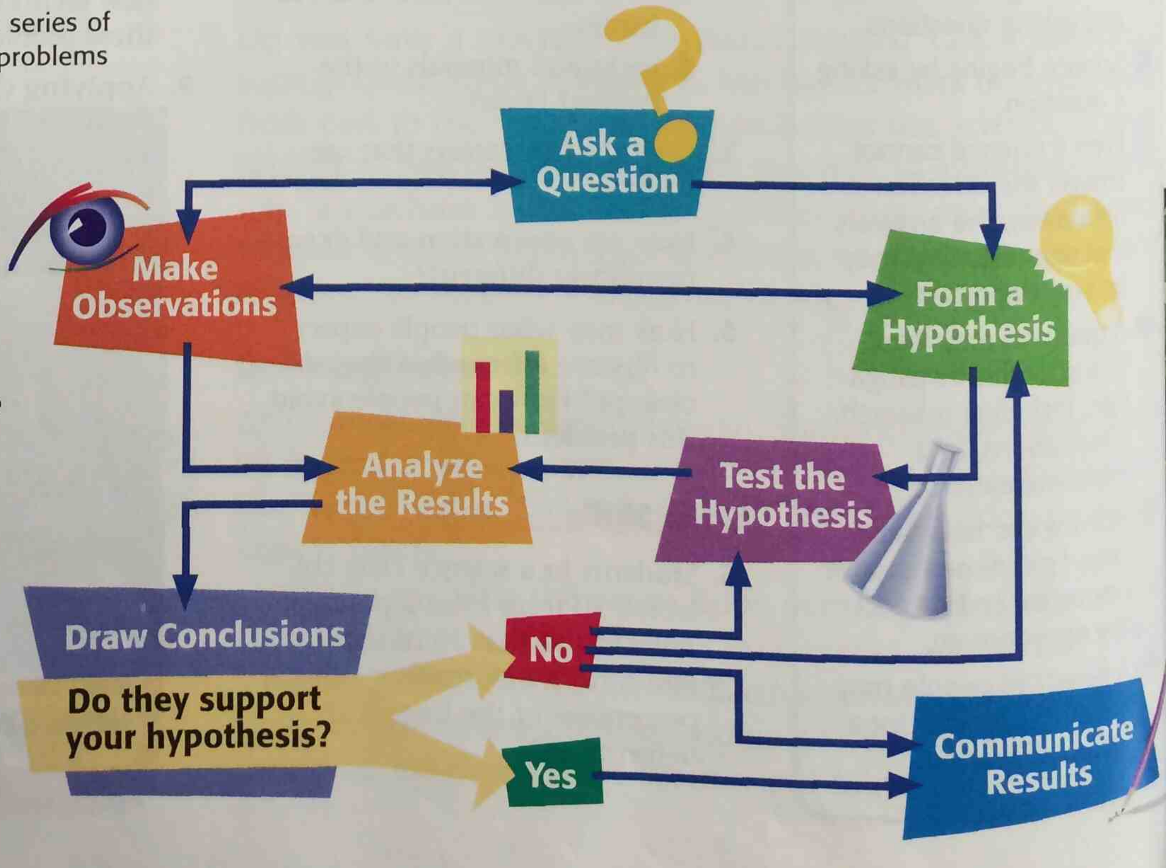


Figure 1 *Scientific methods often include the same steps, but the steps may not be used in the same order every time.*

Ask a Question

Have you ever observed something out of the ordinary or difficult to explain? Such an observation usually raises questions. For example, about the deformed frogs you might ask, "Could something in the water be causing the frog deformities?" Looking for answers may include making more observations.

Make Observations

After the students in Minnesota realized something was wrong with the frogs, they decided to make additional, careful observations, as shown in **Figure 2.** They counted the number of deformed frogs and the number of normal frogs they caught. They also photographed the frogs, took measurements, and wrote a thorough description of each frog.

In addition, the students collected data on other organisms living in the pond. They also conducted many tests on the pond water and measured things such as the level of acidity. The students carefully recorded their data and observations.

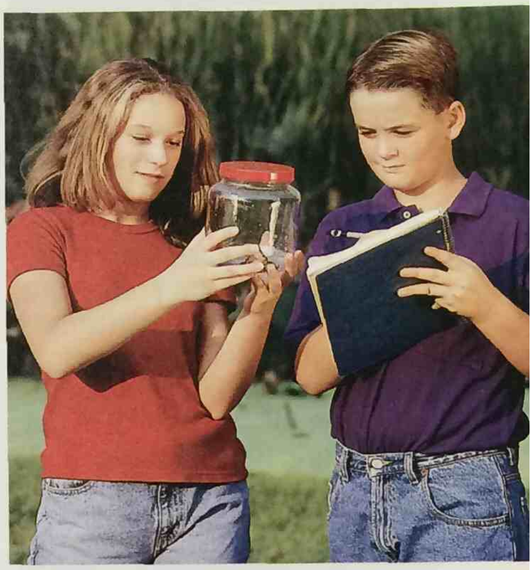


Figure 2 *Making careful observations is often the first step in an investigation.*

Accurate Observations

Any information that you gather through your senses is an observation. Observations can take many forms. They may be measurements of length, volume, time, speed, or loudness. They may describe the color or shape of an organism. Or they may record the behavior of organisms in an area. The range of observations that a scientist can make is endless. But no matter what observations reveal, they are useful only if they are accurately made and recorded. Scientists use many standard tools and methods to make and record observations. Examples of these tools are shown in **Figure 3.**

Figure 3 *Microscopes, rulers, and thermometers are some of the many tools scientists use to collect information.*

Form a Hypothesis

After asking questions and making observations, scientists may form a hypothesis. A **hypothesis** (hie PAHTH uh sis) is a possible explanation or answer to a question. A good hypothesis is based on observation and can be tested. When scientists form hypotheses, they think logically and creatively and consider what they already know.

To be useful, a hypothesis must be testable. A hypothesis is testable if an experiment can be designed to test the hypothesis. Yet if a hypothesis is not testable, it is not always wrong. An untestable hypothesis is simply one that cannot be supported or disproved. Sometimes, it may be impossible to gather enough observations to test a hypothesis.

Scientists may form different hypotheses for the same problem. In the case of the Minnesota frogs, scientists formed the hypotheses shown in **Figure 4.** Were any of these explanations correct? To find out, scientists had to test each hypothesis.

Reading Check **What makes a hypothesis testable?**

CONNECTION TO Environmental Science

WRITING SKILL Minnesota's Deformed Frogs

Deformed frogs were first noticed in Minnesota in 1995. In 1996, the Minnesota Pollution Control Agency (MPCA) began studying the problem. It funded and coordinated studies searching for the causes of the deformities. Find out what the MPCA is doing about the deformed frogs today, and write a short summary of what the MPCA has discovered.

hypothesis an explanation that is based on prior scientific research or observations and that can be tested

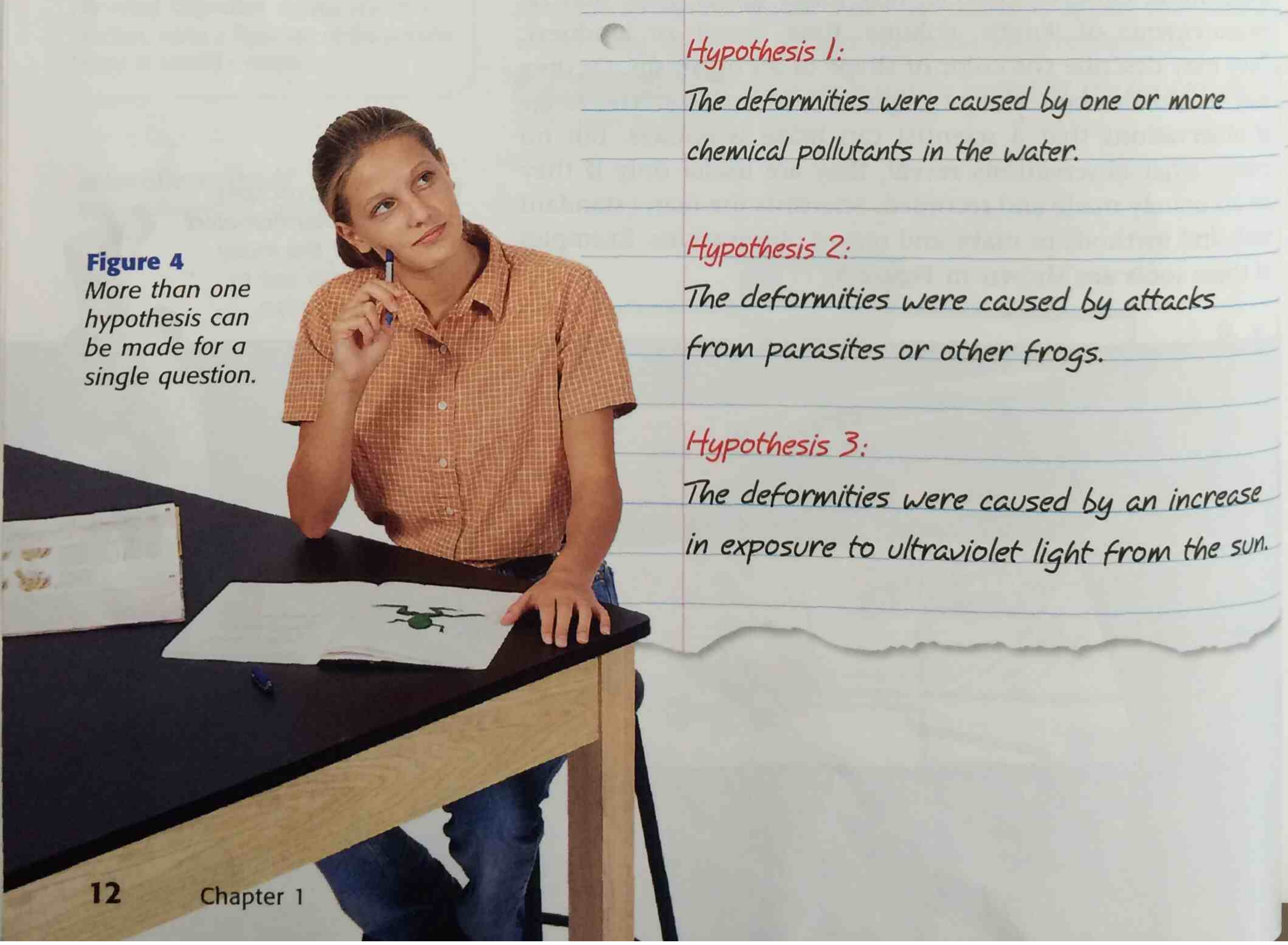


Figure 4 *More than one hypothesis can be made for a single question.*

Predictions

Before scientists can test a hypothesis, they must first make predictions. A prediction is a statement of cause and effect that can be used to set up a test for a hypothesis. Predictions are usually stated in an if-then format, as shown in **Figure 5.**

Figure 5 lists the predictions made for the hypotheses shown in **Figure 4.** More than one prediction may be made for each hypothesis. After predictions are made, scientists can conduct experiments to see which predictions, if any, prove to be true and support the hypotheses.

Figure 5 *More than one prediction may be made for a single hypothesis.*

Hypothesis 1:

Prediction: If a substance in the pond water is causing the deformities, then the water from ponds that have deformed frogs will be different from the water from ponds in which no abnormal frogs have been found.

Prediction: If a substance in the pond water is causing the deformities, then some tadpoles will develop deformities when they are raised in pond water collected from ponds that have deformed frogs.

Hypothesis 2:

Prediction: If a parasite is causing the deformities, then this parasite will be found more often in frogs that have deformities.

Hypothesis 3:

Prediction: If an increase in exposure to ultraviolet light is causing the deformities, then some frog eggs exposed to ultraviolet light in a laboratory will develop into deformed frogs.

CONNECTION TO Language Arts

WRITING SKILL **"Leading doctors say . . ."** Suppose that you and a friend see an ad for a cold remedy on TV. According to the ad, "Leading doctors recommend this product for their patients." Then, a famous actor comes on and says that he or she uses the product, too. Write a dialogue of the debate you might have with your friend about whether these claims are believable.

Figure 6 *Many factors affect this tadpole in the wild. These factors include chemicals, light, temperature, and parasites.*

Test the Hypothesis

After scientists make a prediction, they test the hypothesis. Scientists try to design experiments that will clearly show whether a particular factor caused an observed outcome. In an experiment, a *factor* is anything that can influence the experiment's outcome. Factors can be anything from temperature to the type of organism being studied.

Under Control

Scientists studying the frogs in Minnesota observed many factors that affect the development of frogs in the wild, as shown in **Figure 6.** But it was hard to tell which factor could be causing the deformities. To sort factors out, scientists perform controlled experiments. A **controlled experiment** tests only one factor at a time and consists of a control group and one or more experimental groups. All of the factors for the control group and the experimental groups are the same except for one. The one factor that differs is called the **variable.** Because only the variable differs between the control group and the experimental groups, any differences observed in the outcome of the experiment are probably caused by the variable.

Reading Check How many factors should an experiment test?

controlled experiment an experiment that tests only one factor at a time by using a comparison of a control group with an experimental group

variable a factor that changes in an experiment in order to test a hypothesis

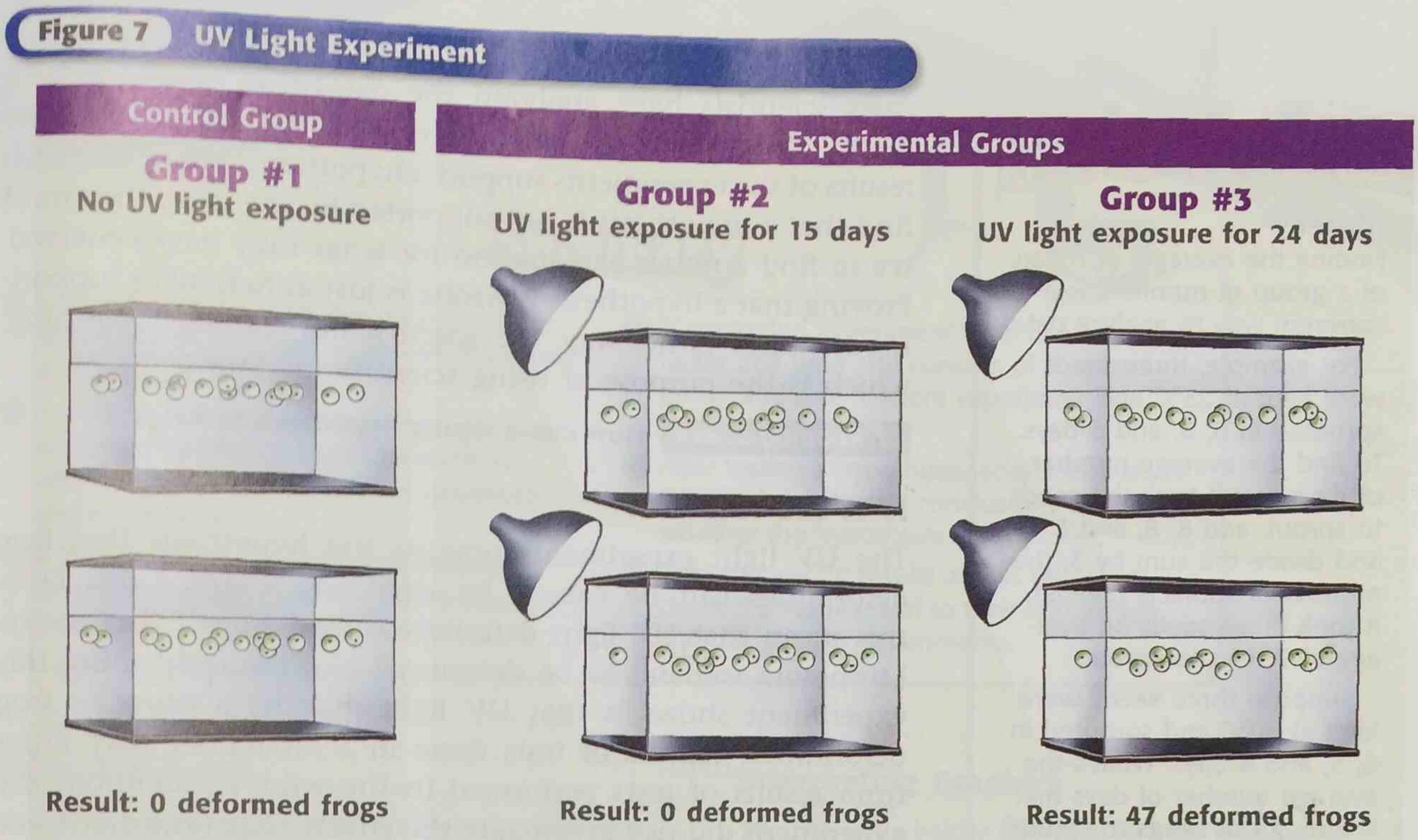
Designing an Experiment

Designing a good experiment requires planning. Every factor should be considered. Examine the prediction for Hypothesis 3: *If an increase in exposure to ultraviolet light is causing the deformities, then some frog eggs exposed to ultraviolet light in a laboratory will develop into deformed frogs.* An experiment to test this hypothesis is summarized in **Table 1.** In this case, the variable is the length of time the eggs are exposed to ultraviolet (UV) light. All other factors, such as the temperature of the water, are the same in the control group and in the experimental groups.

Table 1 **Experiment to Test Effect of UV Light on Frogs**

Group	Control factors			Variable
	Kind of frog	Number of Eggs	Temperature of water	UV light exposure
#1 (control)	leopard frog	100	25°C	0 days
#2 (experimental)	leopard frog	100	25°C	15 days
#3 (experimental)	leopard frog	100	25°C	24 days

Figure 7 UV Light Experiment



Collecting Data

Figure 7 shows the experimental setup to test Hypothesis 3. As **Table 1** shows, there are 100 eggs in each group. Scientists always try to test many individuals. They want to be sure that differences between control and experimental groups are caused by the variable and not by differences between individuals. The larger the groups are, the smaller the effect of a difference between individual frogs will be. The larger the groups are, the more likely it is that the variable is responsible for any changes and the more accurate the data collected are likely to be.

Scientists test a result by repeating the experiment. If an experiment gives the same results each time, scientists are more certain about the variable's effect on the outcome. Scientists keep clear, accurate, honest records of their data so that other scientists can repeat the experiment and verify the results.

Analyze the Results

After scientists finish their tests, they must organize their data and analyze the results. Scientists may organize data in a table or a graph. The data collected from the UV light experiment are shown in the bar graph in **Figure 8.** Analyzing the results helps scientists explain and focus on the effect of the variable. For example, the graph shows that the length of UV exposure has an effect on the development of frog deformities.

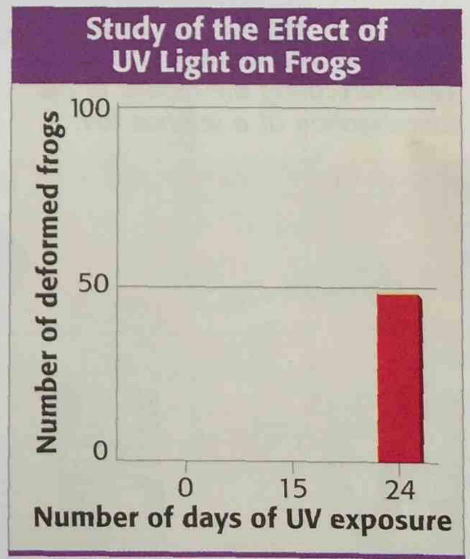


Figure 8 *This graph shows that 24 days of UV exposure had an effect on frog deformities, while less exposure had no effect.*

Math Practice

Averages

Finding the average, or mean, of a group of numbers is a common way to analyze data.

For example, three seeds were kept at 25°C and sprouted in 8, 8, and 5 days. To find the average number of days that it took the seeds to sprout, add 8, 8, and 5 and divide the sum by 3, the number of subjects (seeds). It took these seeds an average of 7 days to sprout.

Suppose three seeds were kept at 30°C and sprouted in 6, 5, and 4 days. What's the average number of days that it took these seeds to sprout?

Draw Conclusions

After scientists have analyzed the data from several experiments, they can draw conclusions. They decide whether the results of the experiments support a hypothesis. When scientists find that a hypothesis is not supported by the tests, they must try to find another explanation for what they have observed. Proving that a hypothesis is wrong is just as helpful as supporting it. Why? Either way, the scientist has learned something, which is the purpose of using scientific methods.

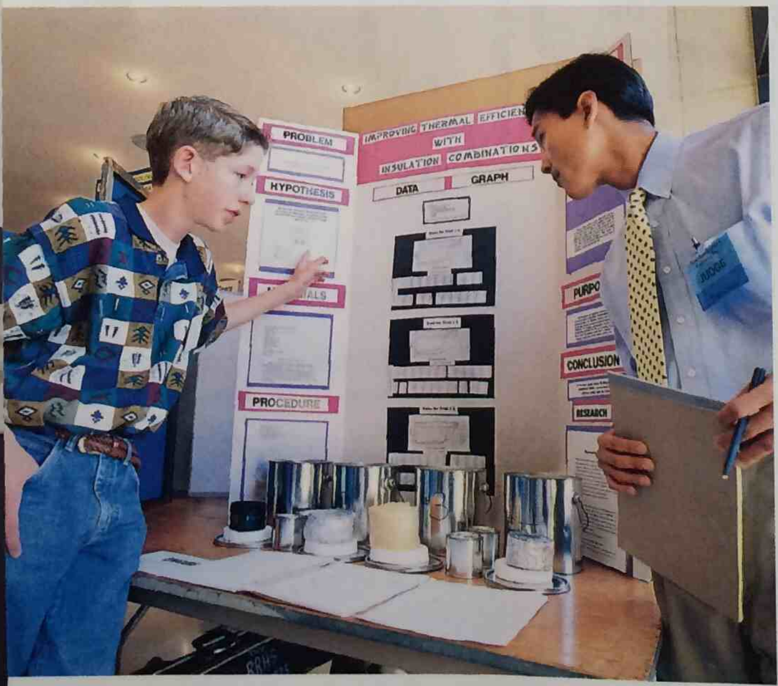
Reading Check **How can a wrong hypothesis be helpful?**

Is It the Answer?

The UV light experiment supports the hypothesis that frog deformities can be caused by exposure to UV light. Does this mean that UV light definitely caused frogs living in the Minnesota wetland to be deformed? No, the only thing this experiment shows is that UV light may be a cause of frog deformities. Results of tests done in a laboratory may differ from results of tests performed in the wild. In addition, the experiment did not investigate the effects of parasites or some other substance on the frogs. In fact, many scientists now think that more than one factor could be causing the deformities.

Sometimes, similar investigations or experiments give different results. For example, another research team may have had results that did not support the UV light hypothesis. In such a case, scientists must work together to decide if the differences in the results are scientifically significant. Often, making that decision takes more experiments and more evidence.

Figure 9 *This student scientist is communicating the results of his investigation at a science fair.*



Communicate Results

Scientists form a global community. After scientists complete their investigations, they communicate their results to other scientists. The student in **Figure 9** is explaining the results of a science project.

Scientists regularly share their results for several reasons. First, other scientists may then repeat the experiments to see if they get the same results. Second, the information can be considered by other scientists with similar interests. The scientists can then compare hypotheses and form consistent explanations. New data may strengthen existing hypotheses or show that the hypotheses need to be altered. There are many paths from observations and questions to communicating results.