1.2 The Nature of Scientific Inquiry

Scientific inquiry is a general term that refers to the different processes and methods that scientists use to investigate the natural world. The word *inquiry* (from the root word "inquire") means "question" or "investigation." This is a very appropriate word since all scientific investigations explore a question.

Types of Scientific Inquiry

LEARNING TIP
Before you read Table 1, read the title. What is the purpose of the table? Pay attention to the headings because they tell you what is important in the different parts of the table.

All scientific investigations use similar processes to find answers to questions. In most cases, these processes attempt to identify relationships between variables. A **variable** is any condition that could change in an investigation. In some cases, the investigator can change or control the variables; in other cases the variables cannot be changed or controlled. The methods used in scientific inquiry depend, to a large degree, on the purpose of the inquiry and on the nature of the variables (Table 1).

Table 1 Examples of Different Types of Scientific Inquiry

Type of inquiry	Question	Design
Controlled experiment	What is the effect of acid rain on the growth of plants?	Three vinegar solutions, with different pH values, will be used to simulate acid rain. Distilled water (pH = 7) will be used as a standard for comparison. Four plants will be watered with these solutions from the time the seeds are placed in the soil. The independent variable will be the pH of the solutions. The dependent variable will be the growth of the plants. All other variables (light, nutrients, temperature, and time) will be controlled. The growth will be determined by measuring the height of the plants, as well as the total surface area of the leaves. The general appearance of the plant (e.g., colour) will also be considered.
Correlational study	Is there a statistical relationship between smoking and heart disease?	The most recent statistics from Statistics Canada will be used to determine the percentage of the general public who smoke. This information can be broken down by gender and age group. Anonymous medical records of an appropriate sample of individuals experiencing some form of heart disease will be used to determine the percentage of heart disease patients who smoke. This will be controlled for gender, age group, and life-style factors so that fair comparisons can be made. An analysis of the data will show any correlation between the two variables, smoking and heart disease.
Observational study	Do a greater percentage of the male population or the female population smoke?	The sample or survey method will be used to determine which gender of the population has the higher percentage of smokers. A representative sample of equal numbers of males and females will be interviewed and asked whether they smoke. The individuals will be randomly selected from the population to ensure that all ages, socioeconomic backgrounds, ethnic origins, and other characteristics are represented. The inquiry can be modified by asking the age range of the individuals to determine the percentage of smokers in the different age groups.

If the purpose of an investigation is to determine the relationship between two variables—for example, the voltage and the current in an electric circuit—then you can carry out a **controlled experiment**. This means that you can control the variables. If the purpose of an investigation is to test a suspected relationship between two variables—for example, automobile speed and the number of highway deaths—a controlled experiment is not possible. (It is not appropriate to create crashes on the highway to see if higher speeds cause more deaths.) Instead, you can conduct a **correlational study**. If the purpose of an investigation is to describe and understand a natural phenomenon—for example, the rotation of the Moon around Earth or the rings of Saturn—neither a controlled experiment nor a correlational study is appropriate. The investigator must rely on extensive observations in order to describe the phenomenon. An **observational study** is used when the investigator is unable to, or does not wish to, control the variables. In both correlational and observational studies, it is difficult, if not impossible, to determine cause and effect.

Controlled Experiments

A controlled experiment is a test in which one variable is systematically changed to determine its effect (if any) on a second variable. An attempt is made to control all the other variables—that is, to hold them constant. This allows researchers to be reasonably confident that any outcomes were caused by the variable that was changed. The ability to control variables makes a controlled experiment different from other types of scientific inquiry. For example, you may observe that the maple trees in your area do not look very healthy: it is mid-summer, but the leaves are faded and small, and they have yellow spots on them. You ask yourself what is causing this problem with the leaves. You may suggest a number of possible answers to explain your observations. For example, you may think that insects are attacking the trees or a disease has been introduced. Since all the leaves on the trees are affected, you think that maybe acid rain is causing the problem. This is your hypothesis. A hypothesis is a possible explanation for your initial observations. From your hypothesis, you can make a prediction that can be tested in a controlled experiment. For example, if acid rain is causing the problem with the leaves of maple trees, then you predict that maple seedlings in a greenhouse will experience the same problem if they are sprayed with water of the same acidity as the acid rain (Figure 1).

Figure 1 A controlled experiment can help us understand the effects of acid rain on maple seedlings.

LEARNING TIP

Different methods can be used to help you understand new vocabulary. As you read the words in bold, focus on the examples. How do the examples help you understand the meanings of new terms?

In a controlled experiment, you attempt to identify all the different conditions (variables) that could affect the experiment. The variable that you, the investigator, change is called the **independent variable.** In a controlled experiment, you change only one variable. The variable that changes in response to the change in the independent variable is called the **dependent variable** because its value "depends" on the change in the independent variable. All the other possible causes of the result are kept constant and are known as **controlled variables.** By controlling all the other variables, you can be reasonably certain that the change in the independent variable caused any observed change in the dependent variable. In the maple tree example, the controlled variables (light, nutrients, and temperature) are kept constant, so you can be reasonably certain that the acid rain (the independent variable) caused a change in the health of the maple leaves (the dependent variable).

In a controlled experiment, it is important to include a control. A **control** is a setup that acts as a standard or reference with which the results from the experiment can be compared. A control group is necessary to enable the investigator to determine that the changes in the independent variable caused the changes in the dependent variable. In the maple tree example, trees that are sprayed with pure, non-acidic water act as the control because you suspect (assume) that pure water will not have a damaging effect on the leaves. If all the other variables are kept constant, then you can be reasonably certain that the acid rain damaged the leaves. 1A Investigation

1A Investigation

Get in the Swing: Controlling Variables

To perform this investigation, turn to page 30.

In this investigation, you will control variables to see what effect they have on a swinging pendulum.

Correlational Studies

In a correlational study, a scientist tries to determine whether one variable is affecting another without purposefully changing or controlling any of the variables. Instead, the variables are allowed to change naturally.

Correlation coefficients indicate the degree of similarity between two sets of data. Correlation coefficients range from -1 to $+1$. A **positive correlation** indicates a direct relationship—that is, an increase in one variable corresponds to an increase in the other variable (Figure 2). A **negative correlation** indicates an inverse relationship—an increase in one variable corresponds to a decrease in the other variable (Figure 3). A correlation of 0 indicates no relationship between two variables (Figure 4). Notice that the points are randomly distributed on the graph.

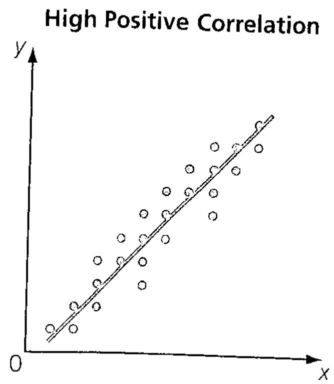

Figure 2 In a positive correlation, variable *y* increases as variable *x* increases.

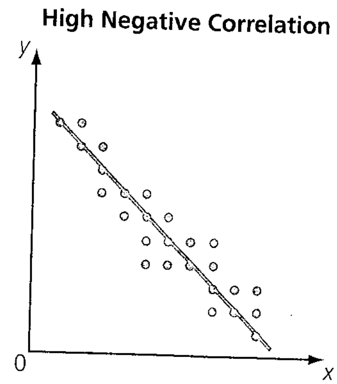

Figure 3 In a negative correlation, variable *y* decreases as variable *x* increases.

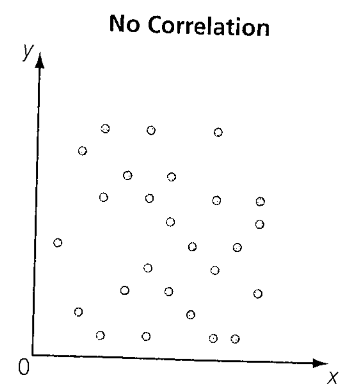

Figure 4 If there is no correlation, there is no pattern in the data.

As an example, consider the relationship between hours of study and exam grades (Table 2 and Figure 5). As you might expect, the correlation between hours of study and exam grades is positive and fairly high. In other words, as the amount of study time increases, so does the grade received. If the correlation between these two variables were +1, this relationship would be true in practically every case. A perfect correlation is unlikely, however, because not everyone who studies hard gets good grades. Two people could spend the same amount of time studying and get different grades. So the correlation between these two variables is somewhere between 0 and +1.

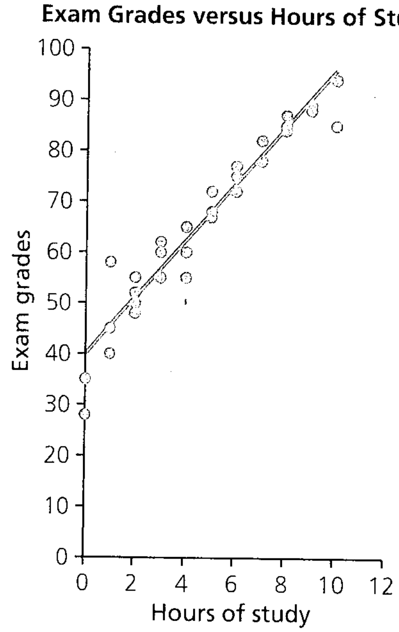

Figure 5 When the data in Table 2 are plotted on a graph, the graph shows a high positive correlation between hours of study and exam grades.

When you know that two variables are correlated (either positively or negatively) you can predict one variable based on your knowledge of the other. Generally, the higher the correlation (either positive or negative) the more probable it is that your prediction will be correct. In the example above, you could predict with some certainty that a person who spends a lot of time studying will get good grades.

Correlational studies require very large sample numbers and many replications to increase the validity of the results. Even then, it is often difficult to establish cause and effect. A correlation between two variables does not indicate that one variable causes an effect on the other. While any two variables can be compared, it is important for a scientist to determine whether a reasonable, plausible link is possible or whether a correlation would be simply a coincidence. As an extreme example, you could graph the annual earthquake tremors in British Columbia against the frequency of car accidents in Vancouver, and possibly discover that the years with the greatest number of earthquake tremors correspond to the years with the greatest number of car accidents. There is no apparent reason for these two variables to correlate, and it is highly unlikely that a reasonable link could be established

Table 2 Hours of Study and Exam Grades for a Class of 30 Students

Student	Hours of study	Exam grades
1	3	55
2	0	28
3	1	45
4	9	88
5	5	68
6	2	50
7	6	77
8	2	48
9	8	85
10	4	55
11	7	82
12	3	60
13	5	67
14	4	65
15	1	58
16	5	72
17	8	87
18	2	55
19	6	75
20	3	62
21	6	72
22	7	78
23	2	52
24	1	40
25	10	94
26	8	84
27	0	35
28	9	89
29	10	85
30	4	60

LEARNING TIP

When you are reading dense text, ask yourself, "Am I on track?" If you find yourself reading without understanding, stop and ask why. Is it because the ideas are difficult, because there are many difficult terms and phrases, or because there are simply too many ideas?

between the two. Any positive or negative correlation is likely due to coincidence. An example of a more reasonable pair of variables to investigate would be mothers drinking alcohol during pregnancy and health problems in infants. A high correlation between these two variables would probably indicate a cause-and-effect relationship because medical research has accumulated a significant amount of data related to the effects of alcohol on fetuses. Since a controlled experiment is not possible, for obvious reasons, the certainty that the consumption of alcohol causes illness in the developing fetus is lower than it could be.

Unfortunately, reports of statistical correlations can be deceiving. For example, a newspaper headline reported that a research study showed a high correlation between student height and reading ability. In other words, taller students are better readers. What the research failed to note (or the newspaper failed to report) is that the study had been done with students of different ages. If the study had been done with students of the same age, there would have likely been no correlation between height and reading ability. If taller students read better than shorter students, it was probably because they were older, not simply because they were taller.

Using correlational studies, investigators can do valid science without doing experiments. They can find relationships between two or more variables by using databases that other researchers have prepared or by making their own observations and measurements through fieldwork, interviews, and surveys.

Observational Studies

The role of careful, systematic observations is often overlooked as a source of scientific knowledge. Science often progresses without the testing of hypotheses or theories. In many cases, hypotheses are generated after the evidence is collected through observation.

Often the purpose of scientific inquiry is simply to study a natural phenomenon with the intention of gathering scientific information to answer a question. Observational studies involve observing a subject or phenomenon in a structured manner—in a way that doesn't interfere with or influence the subject or phenomenon. Observational studies, like all scientific investigations, start with observations that lead to a question, but they may not have a specific hypothesis or plausible explanation. If a hypothesis is not created before the study, it may be generated after many observations, and modified as new information is collected over time.

Sciences such as astronomy, paleontology, and ecology rely heavily on observations because controlled experiments or correlational studies are often difficult, if not impossible, to conduct. For example, the question "Where do monarch butterflies go during the Canadian winter?" can only be answered by systematic observation.

In an observational study, the hypothesis or plausible explanation may not be posed at the beginning of the study, but after considerable evidence has been gathered. For example, the hypothesis that eventually led to Charles Darwin's theory of natural selection was created only after Darwin had made extensive observations during his voyages aboard the *Beagle*.

Like correlational studies, observational studies are done when an investigator cannot control the variables. The reasons for the inability to control the variables include safety, time, distance, cost, and ethics. Think back to the question "Where do monarch butterflies go during the Canadian winter, and how do we know?" Obviously, a scientist could not follow an individual butterfly, or even a group of butterflies, for months at a time to observe directly where butterflies go and how they get there (Figure 6).

A common observational approach used by scientists in such circumstances is a technique known as the capture-recapture method. In the butterfly study, butterflies were captured and tagged (Figure 7). The number on each tag, the date, and the location were then recorded. The butterflies were released back onto the flowers from which they were gathered. When a tagged butterfly was recaptured, the tag number, date, and location were recorded again.

In addition to the tagging, many student volunteers participated in the scientific research by observing monarch butterflies and then submitting their observations to one of the many groups across North America that study monarch butterfly migration. These organizations made all the observations available through their websites and other resources. The observations collected and shared in this way showed the annual migration routes for monarch butterflies, from their summer habitat in the northern United States and southern Canada to their winter habitat in Mexico (Figure 8).

To learn more about monarch butterfly migration, go to **www.science.nelson.com**

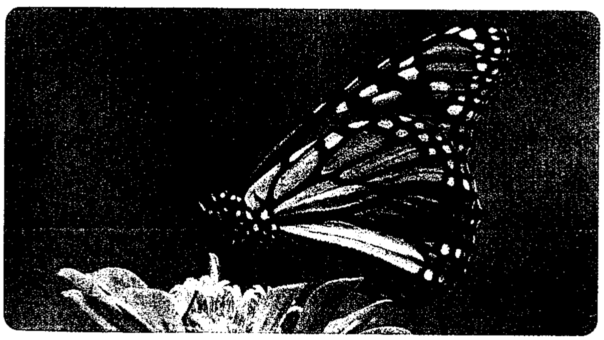

Figure 6 No other butterflies in the world migrate like the monarch butterflies in North America.

Figure 7 A small self-adhesive tag (9 mm in diameter) was placed on the underside of the hind wing. The tag position was close to the centre of gravity of the butterfly and did not appear to interfere with its flight or harm it.

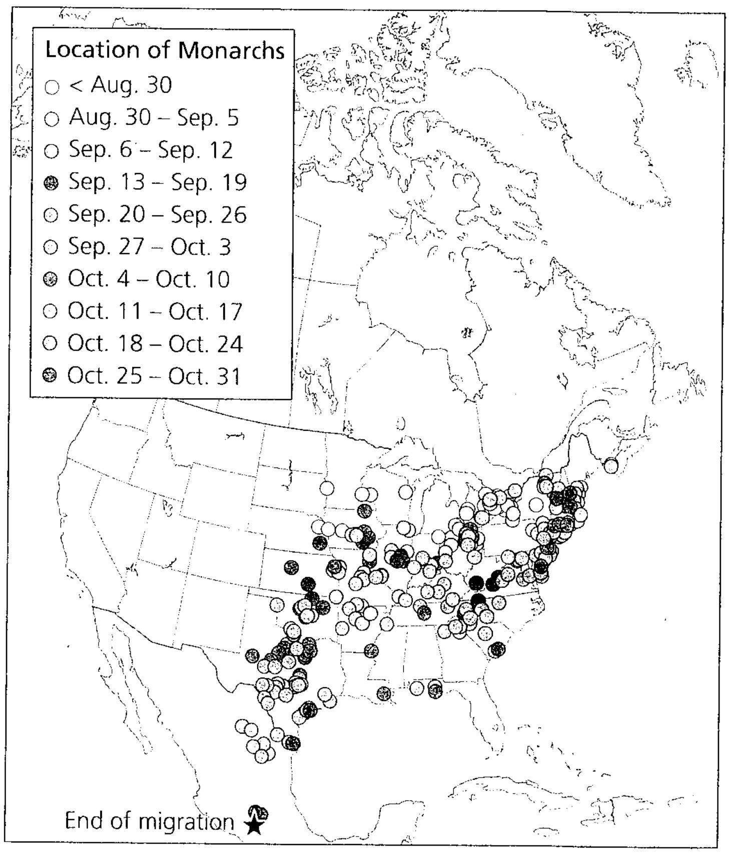

Figure 8 Data collected over time enabled scientists to map the migration route of monarch butterflies.

TRY THIS: Completing the Cube

Skills Focus: questioning, recording, observing, analyzing, evaluating, concluding

Scientists formulate hypotheses and theories by observing and analyzing evidence—using the scientific method. They draw conclusions based on the evidence. The more evidence that is available, the more confident they can be in their conclusions.

In this activity, you will analyze available evidence and draw a conclusion.

Materials: cube with numbers printed on its sides

1. Your teacher will place a cube on your table (Figure 9). You are not allowed to touch the cube!

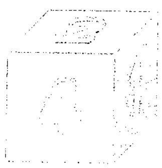

Figure 9

2. In your group, discuss the cube and record any questions you have. What do you want to know about the cube?
3. Carefully observe the five visible sides of the cube, and record all your observations.
4. Based on your observations, draw a conclusion about what is on the bottom of the cube.

A. What evidence did you use to draw your conclusion?

B. How confident are you in your conclusion? Explain.

C. Is your conclusion a fact or a theory? Explain.

D. How is this activity like a scientific investigation?

The Controlled Experiment: An Everyday Example

TIP

You can use a table to help you organize information from your reading. In preparation for reading pages 22 to 28, make a two-column table. In the first column, write the parts of a controlled experiment (see Figure 10 on page 23). In the second column, record important information in point-form notes. Include the terms in your notes.

Figure 10 on page 23 presents a flow chart that illustrates the general scientific method. While this flow chart shows a linear progression from Questioning to Communicating, there are normally many loops back through the process as scientific investigations proceed. At any point in the process, scientists can, and sometimes must, go back to an earlier step or back to the beginning to make revisions or improvements. Recall the definition of the scientific method on page 9.

Scientific inquiry begins with observations. You, as a scientist, make an observation and ask questions such as "How?", "Why?", "What?", "Where?", and "When?" Asking a question is the actual starting point for your scientific research. You can apply the scientific method to an everyday problem. For example, you observe that the grass in a lawn is yellow, not as green as you would expect it to be. You pose a question: "Why is the lawn yellow rather than green?" If you are really interested in finding the answer to the question, you could approach it scientifically and follow a method that would hopefully lead you to the answer.

SAMPLE PROBLEM

Ask Appropriate Questions

Scientific discoveries always generate more questions. Suppose that a chemist has isolated a previously unknown compound from the bark of a yew tree. The chemist has determined the formula of the compound and its physical properties (for example, melting point, density, and reactivity). What questions might the scientist ask about the relationship between the compound and the yew tree, which could be the basis of further research?

Solution

The scientist could ask questions such as these:

- Is this compound found in all yew trees?
- If the compound is not found in all yew trees, then in which yew trees is it found? Is it only present in yew trees of a particular age, or size, or species? Is it only present in yew trees living in a particular climate or type of soil, or at a particular altitude?
- What function or role does the compound play in the yew tree?
- Is the compound produced by the yew tree? If so, where in the yew tree is the compound produced? How is the compound produced by the yew tree?
- At what point in the life of a yew tree is the compound first produced?
- At what point in the evolution of the yew tree was the compound first produced? That is, has the compound always been present in yew trees?
- Is the compound present in any other types of trees, other than the yew tree?

Practice

The Hubble Space Telescope has sent pictures of space back to Earth. In one of the pictures, astronomers detected a new object, which was not visible in previous pictures of this region of space. Write five questions that could guide the astronomers' further research.

Hypothesizing

General questions can be restated or you can pose follow-up questions. "Does the lawn need water?"; "Does the lawn need sunshine?"; "Does the lawn need fertilizer?" For argument's sake, let us assume that you are satisfied that the lawn does not need water or sunshine. So you are left with the question "Does the lawn need fertilizer?" Now the observation and the question can be restated as a hypothesis. A hypothesis is a possible explanation that accounts for the observations you have made. The most important characteristic of a hypothesis is that it must be testable. In other words, you must be able to design a procedure you can use to collect evidence that will either support your hypothesis or lead you to reject it as an explanation of your observations. You must also be able to identify two variables in your hypothesis. Thus, a hypothesis suggests a test of the relationship between two variables: an independent variable and a dependent variable. The hypothesis serves two functions: it suggests an explanation and it guides your investigation in search of support for your suggested explanation or a better explanation. Your hypothesis (possible explanation), then, is that the grass in your lawn is yellow (dependent variable) because it needs fertilizer (independent variable).

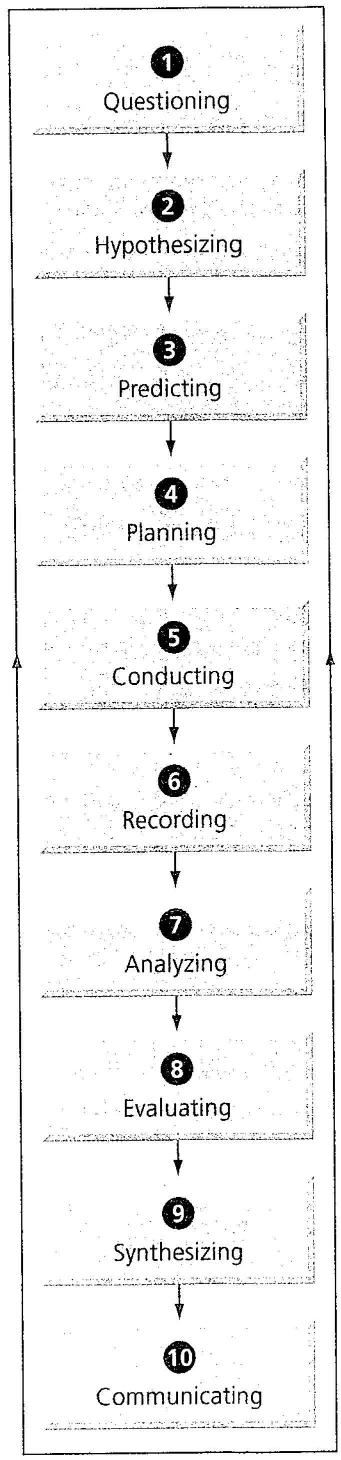

Figure 10 The scientific method is an effective way of answering questions about the natural world.

TRY THIS: Identifying and Creating Hypotheses

Skills Focus: analyzing, evaluating, hypothesizing, communicating

1. Identify each of the following statements as an observation, a fact, a hypothesis, or a theory.
   (a) On June 30, 1908, in Tunguska, Siberia, an explosion equivalent to about 15 million tonnes of TNT occurred.
   (b) The explosion in Tunguska, Siberia, on June 30, 1908, was caused by the collision of a black hole with Earth.
   (c) The explosion in Tunguska, Siberia, on June 30, 1908, was caused by a natural, extraterrestrial phenomenon and not by a human activity.
   (d) On June 30, 1908, a bright, fast-moving object was seen in the sky over Tunguska, Siberia.
   (e) The explosion in Tunguska, Siberia, on June 30, 1908, was caused by the collision of a comet with Earth.
2. Read each of the following statements, and indicate whether it is an appropriate scientific hypothesis. For each statement that you consider to be an appropriate scientific hypothesis, identify the independent and dependent variables.
   (a) Fertilizer affects how big a plant will grow.
   (b) If you buy expensive batteries, they will last longer.
   (c) There are other inhabited planets in the universe.
   (d) The voltage in a circuit determines how fast an electric motor will turn.
   (e) Hamsters are colour-blind.
   (f) Chocolate may cause pimples.
   (g) High temperatures cause children to misbehave.
   (h) Our universe is surrounded by another, larger universe, with which we can have absolutely no contact.
   (i) Temperature will affect the growth of crystals.
   (j) If fermentation rate is related to temperature, then increasing the temperature will increase gas production.
3. For each of the following questions, write a hypothesis that could be tested in an experiment.
   (a) How does sewage in a river affect the level of pollution in the river?
   (b) What is the relationship between the number of hours of light and the number of eggs that chickens will lay?
   (c) How does light affect the reproduction of mould on bread?
   (d) How does music affect the growth of plants?
   (e) How much acid is in soft drinks?
   (f) Which brand of paper towels absorbs the most water?

A hypothesis enables you to make a prediction that can be tested. A hypothesis and a prediction go hand in hand. A hypothesis is an explanation of *why* something happens—the grass is yellow because it needs fertilizer. A prediction is a statement of *what* you think will happen—if I add fertilizer to the lawn, then the grass will turn green again. Thus, your prediction is based on the possible explanation offered by your hypothesis.

Your prediction can now be tested to determine if your hypothesis is an acceptable explanation.

Your next step is to plan an experiment to test your prediction. You need to think of all the steps in the procedure you will use. The design is the procedure, in which you plan to change one variable (the independent variable), measure the effect on another variable (the dependent variable), and, if possible, keep all other variables constant (controlled variables). In your lawn problem, you will add fertilizer to the lawn (the independent variable), observe its effect on the colour of the grass (the dependent variable), and try to keep all other variables (such as water and sunshine) constant.

If you want to approach your problem scientifically, there is another important consideration. Since you will be conducting a controlled experiment, you must have some way of knowing for sure that any change in the dependent variable (colour of the grass) was caused by the independent variable (fertilizer). Otherwise, if the grass turned green, you could never be certain that this was caused by the fertilizer. You need a control.

To have a control, you could split the lawn into two parts: one part gets the fertilizer (experimental treatment) and the other part does not (control). Everything else remains the same. The part that does not receive the fertilizer treatment acts as a control or standard that you can compare with the experimental setup. If the grass in the experimental half turns green and the grass in the control half remains yellow, you can be fairly confident that the fertilizer was the cause. Your prediction and your hypothesis would be supported.

Another consideration in the planning stage is identifying the materials and equipment that you will need to perform your experiment. For the lawn experiment, the list is fairly short: wooden stakes and string to divide the lawn in half, lawn fertilizer, fertilizer spreader, camera, paper, and pencil.

Always keep safety in mind during your planning. Do any of the materials or procedures pose a risk to you or others? For example, it might be wise to wear a mask while you are spreading the fertilizer on the lawn. It might also be wise to post a sign, advising others that fertilizer has been applied.

Scientific investigations require careful observations. You need to think carefully about what you are going to measure or observe and how you are going to record your observations. If possible, create tables to record your observations, especially when the observations involve measurements.

Conducting

After you have planned an experiment, you put your plan into action—you conduct the experiment. It is important to follow the procedure you developed during the planning stage. As you carry out the experiment, you may find it necessary to modify the procedure. You should record any modifications to the procedure in case you or someone else wants to repeat the experiment.

In your lawn experiment, you apply the fertilizer to half of the lawn, keep all the other variables constant, and make observations at regular intervals for a reasonable period of time.

Recording

As you carry out an experiment, you need to record your observations at regular intervals. Often, you will have to make quantitative (numerical) and qualitative (non-numerical) observations.

An observation is information that you get through your senses. You observe that a rose is red and has a sweet scent, or you observe that the grass on a lawn is yellow. When people describe the qualities of objects and events, without any reference to a measurement, the observations are said to be **qualitative observations**. Common qualitative observations include the state of matter (solid, liquid, or gas), colour, and odour. These qualities cannot be

LEARNING **TIP**

Check your understanding of the terms qualitative and quantitative by explaining the differences to a partner.

measured directly but must be described in words. As you record the results of your experiments, be sure to include your qualitative observations.

Qualitative observations can be recorded using words or pictures. A camera would be an appropriate tool for recording qualitative observations. Sometimes, however, it is more appropriate to draw or sketch these observations.

Observations that are based on measurements or counting are **quantitative observations**, since they deal with quantities of things. The length of a rose's stem, the number of petals, and the number of leaves are quantitative observations.

For your lawn experiment, you will have to make qualitative observations, and photographs would be an appropriate way to record these observations. Simply take photographs of the experimental and control parts of the lawn at regular intervals during the experiment. Ensure that the photographs are labelled appropriately, and write notes to accompany each photograph.

Analyzing

While tables are useful for organizing your observations, they are usually not the final product of an investigation. Looking at your table and analyzing, or carefully studying, your qualitative and quantitative observations can usually give you a lot of information. As well, you can plot graphs to make better sense of your quantitative observations. Graphs make it easier to see patterns in your observations.

Analyzing your observations will also help you identify any errors in your measurements. Any measurement that is clearly very different from the others should be carefully checked. If the very different measurement is found to be caused by an error in measurement, then it should not be used in your analysis.

Arrange the pictures and accompanying notes on the experimental and control areas in sequence. This will provide a visual and written record of any changes that took place.

The goal of carrying out an investigation is to answer the question that you asked at the beginning. When you create a hypothesis or make a prediction, you are suggesting an answer to the question. This suggested answer is based only on the information that was available to you before starting the investigation. Analyzing the observations you recorded during the investigation may provide the evidence you need to answer the question with more certainty.

If the evidence gathered confirms the prediction, you can have more confidence that your hypothesis is acceptable. Remember, though, that it does not prove that your hypothesis is true. If the evidence gathered does not support your prediction, then you would likely think that your hypothesis is not an acceptable explanation. Don't worry if your hypothesis is not supported—scientists usually need to revise and repeat experiments many times. Remember that science is a repetitive process.

Learning that your hypothesis is not supported is just as valuable as learning that it is supported. For example, assuming you are satisfied that the design of your lawn experiment was appropriate, you would be more certain that it was not the lack of fertilizer that caused the grass to be yellow. You have eliminated one variable as a possible cause of your observations, and you now need a new or revised hypothesis.

Evaluating

It is always important to reflect on events in order to learn from them. This is one aspect of science that is sometimes neglected. You need to think about and evaluate two parts of the investigation: the design and procedure you followed, and the observations you made.

Once you have been through a scientific inquiry, you need to step back and think about what you did and how you did it. What went well? What were the challenges? What would you do differently if you were to go through the process again?

When reflecting on a scientific inquiry, you must judge how good the evidence is in order to decide whether it supports your hypothesis or prediction. You need to identify the types and sources of errors that may have been made while the observations were being collected. Any sources of error should be identified in the conclusion, or discussion of your results, and should be used as the basis for improving the process the next time.

For example, when reflecting on your lawn experiment, you should think about several aspects of the process:

- Were there any flaws in the design? Were two sections adequate? Should you have divided the lawn into four, or six, or ten sections, and then selected half of the sections at random to receive the fertilizer treatment? Are you satisfied that all other variables (such as water and sunshine) were kept constant in all sections of the lawn?
- You should evaluate the observations you made. Did your observations (for example, your photographs and notes) accurately reflect the changes that occurred in the lawn during the investigation period? Was the evidence sufficient and convincing? Did it allow you to decide whether it supports the hypothesis or prediction?
- Were the materials and equipment of suitable quality to do the experiment? Did the fertilizer spreader spread the fertilizer evenly over the experimental area? Did the camera capture good quality photographs?
- Did you or your partners have the skills needed to use the equipment? Did you use the camera properly so that it captured good quality pictures?

Synthesizing

In the final step, you focus on two tasks: determining what you can do with the information obtained from the investigation, and deciding where the investigation might lead.

First you ask, "So what? Now that I've learned something, or gained some new knowledge, what do I do with it? How could the information obtained in this investigation be used?" You should think about if, and how, the new information can be applied to solve real-life problems. Did you learn something about lawn care that you could use in the future? Could you help any friends with their lawn problems?

Work in science seldom ends with a single experiment. Sometimes other investigators repeat the experiment to see if the evidence is the same. More often, the analysis and evaluation of one experiment raise more questions that can be used to create new, related experiments. The following guidelines may help you suggest further experiments:

- Review the evaluation of the evidence. You may suggest repeating the experiment using a new or improved design, better equipment, a revised procedure, or better skills.
- Review the design of the experiment, and focus on the variables. Can a controlled variable become the independent variable in another experiment? Can the dependent variable be changed or measured in a different way?
- Review your hypothesis or prediction. Look for new ways to test it. If the evidence did not support your hypothesis, suggest a new hypothesis that would lead to new experiments.

Communicating

One of the important characteristics of scientific inquiry is that scientists share their information with the scientific community. Clear and accurate communication is essential for sharing information.

TRY THIS: Getting Your Message Across

Skills Focus: recording, conducting, analyzing

Accurate communication is as important in science as it is in everyday life. In this activity, you will work with a partner to develop your communication skills.

1. You and your partner should each choose a common everyday task, such as tying your shoes (or tying a special knot), making a toasted cheese sandwich, going from your school to a sports store across the city, installing a piece of software on your computer, or copying music from your computer to your MP3 player.
2. Write a set of detailed instructions that should enable someone else to complete the task.
3. Exchange tasks with your partner, and read each other's instructions.
4. The test of successful communication is whether your partner can complete the task without asking any questions. If necessary, complete the task at home and report to your partner the following day.

A. Why is clear, accurate communication difficult?

B. What skills do you need in order to communicate clearly? What do you need to do to develop these skills?

C. What strategy did you use to make your communication as clear as possible?

D. What problems did your partner have with your instructions? What could you do in the future to avoid such problems?

The most common method for communicating with others about an investigation is by writing a lab report. A lab report describes the design of the experiment, how it was carried out, the results obtained, an analysis of these results, and any conclusions that can be drawn. A lab report should be written in detail and with clarity so that another person could use it as a set of instructions or pattern to conduct the same investigation.

A lab report is prepared after an investigation is completed. To ensure that you can accurately describe the investigation, it is important to keep thorough and accurate records as you carry out the investigation. Refer to the Skills Handbook, page 556, Writing A Lab Report.

TRY THIS: Solving the Puzzle

Skills Focus: conducting, observing, analyzing, communicating, hypothesizing

Scientists formulate hypotheses and theories by observing and analyzing evidence—using the scientific method. In this activity, you will assemble evidence over time and communicate with fellow scientists, or teams of scientists, to experience the nature of science and understand its challenges.

Materials: envelope containing pieces of a jigsaw puzzle

1. In your group, examine and try to assemble the pieces of a puzzle.
2. Propose a brief description of the complete puzzle picture based on the pieces of puzzle you have. Share your description with the class.
3. On your teacher's direction, join with another group and share your proposed description of the complete picture. Try to combine your puzzle pieces with the other group's puzzle pieces.
4. Revise your proposed description of the complete picture. Your revised description should also be shared with the class.
5. Keep combining your puzzle pieces with other groups until you have as complete a picture as possible. After each combination discuss and revise your description. Write a final description of the picture after all pieces of the puzzle are assembled.

A. Compare the process you followed in this activity with a scientific inquiry. Use the following terms in your comparison: *observation*, *scientific method*, *hypothesis*, *communication*, *evidence*, and *theory.*

B. What type of scientific inquiry is represented here? Explain.

C. What is the significance of having an incomplete puzzle?

D. What are some of the challenges you might expect during a scientific inquiry?