Science Skills

Basic Process Skills

During a science course, you often carry out some short lab activities as well as more detailed experiments. Here are some skills that you will use as you work.

Observing

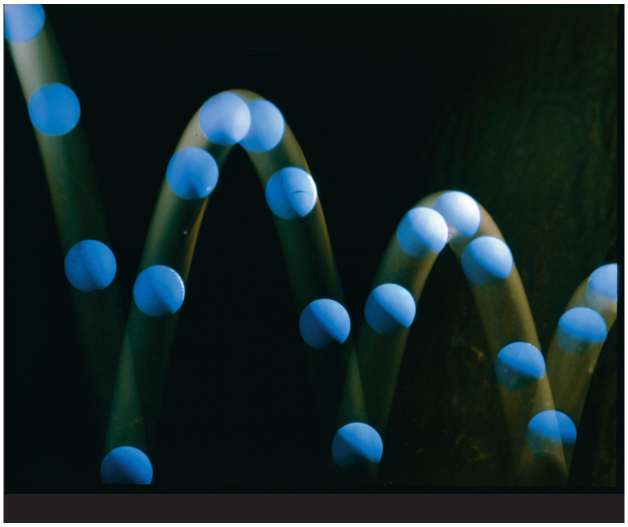
In every science activity, you make a variety of observations. **Observing** is using one or more of the five senses to gather information. Many observations involve the senses of sight, hearing, touch, and smell.

Sometimes you will use tools that increase the power of your senses or make observations more precise. For example, hand lenses enable you to see things in greater detail. Tools may help you eliminate personal opinions or preferences.

In science it is customary to record your observations at the time they are made, usually by writing or drawing in a notebook. You may occasionally make records by using computers, cameras, videotapes, and other tools. As a rule, scientists keep complete accounts of their observations, often using tables to help organize their observations in a regular way.

Inferring

In science as in everyday life, observations are usually followed by inferences. **Inferring** is interpreting an observation or statement based on prior knowledge. For example, you can make several observations using the strobe photograph below. You can observe that the ball is moving. Based on the motion of the ball, you might infer that the ball was thrown downward at an angle by an experimenter. In making that inference, you would use your knowledge about the motion of projectiles. Someone who knew more about projectile motion might infer that the ball loses energy with each bounce. That is why the height decreases with each bounce.



Richard Megna/Fundamental Photographs

Notice that an inference is an act of reasoning, not a fact. That means an inference may be logical but not true. It is often necessary to gather further information before you can be confident that an inference is correct. For scientists, that information may come from further observations or from research into the work done by others.

Comparing Observations and Inferences

Sample Observation	Sample Inference
The ball moves less and less vertical distance in the time between each flash of the strobe light.	Gravity is slowing down the ball's upward motion.
The ball moves the same distance to the right in the time between each flash of the strobe light.	Air resistance is so small that it does not slow down the ball's horizontal motion.

Predicting

People often make predictions, but their statements about the future could be either guesses or inferences. In science, a **prediction** is an inference about a future event based on evidence, experience, or knowledge. For example, you can say, *On the first day next month, it will be sunny all day.* If your statement is based on evidence of weather patterns in the area, then the prediction is scientific. If the statement was made without considering any evidence, it's just a guess.

Predictions play a major role in science because they offer scientists a way to test ideas. If scientists understand an event or the properties of a particular object, they should be able to make accurate predictions about that event or object. Some predictions can be tested simply by making observations. For others, carefully designed experiments are needed.

Measuring

Measurements are important in science because they provide specific information and help observers avoid bias. **Measuring** is comparing an object or process to a standard. Scientists use a common set of standards, called the International System of Units, abbreviated as SI (for its French name, *Système International d'Unités*).

What distance does the ball travel in each time interval in the strobe photograph? You can make measurements on the photograph to make more precise statements about the ball's motion.

Calculating

Once scientists have made measurements, calculations are a very important part of analyzing data. How fast is a ball moving? You could directly measure the speed of a ball using probeware such as a motion sensor. But you can also calculate the speed using distance and time measurements. **Calculating** is a process in which a person uses mathematical operations to manipulate numbers and symbols.

Classifying

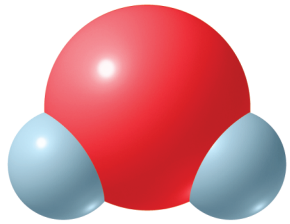
Classifying is grouping items according to some organizing idea or system. Classifying occurs in every branch of science but it's especially important in chemistry because there are so many different ways that elements can combine to form compounds.

Sometimes you place objects into groups using an established system. Other times you create a system by observing a variety of objects and identifying their properties. For example, you could group household cleaners into those that are abrasive and those that are not. Or you could categorize cleaners as toxic or nontoxic. Ammonia is toxic, whereas vinegar is not.

Russ Lappa

Using Tables and Graphs

Scientists represent and organize data in tables and graphs as part of experiments and other activities. Organizing data in tables and graphs makes it easier to see patterns in data. Scientists analyze and interpret data tables and graphs to determine the relationship of one variable to another and to make predictions based on the data.



Space-filling model

Electron dot model

Using Models

Some cities refuse to approve new tall buildings if they would cast shadows on existing parks. As architects plan buildings in such locations, they use models to show where a proposed building's shadow will fall at any time of day at any season of the year. A **model** is a mental or physical representation of an object, process, or event. In science, models are usually made to help people understand natural objects and the processes that affect these objects.

Models can be varied. Mental models, such as mathematical equations, can represent some kinds of ideas or processes. For example, the equation for the surface area of a sphere can model the surface of Earth, enabling scientists to determine its size. Models can be two-dimensional (flat) or three-dimensional (having depth). In chemistry, for example, there are several ways to model the arrangement of atoms in a molecule. Two models for a water molecule are shown above. The electron dot model is two-dimensional. It has the advantage of clearly showing how electrons are shared among atoms in the molecule. The space-filling model cannot show the number of electrons inside the atoms or between atoms, but it does show the arrangement of atoms in space.

Experimental Methods

A science experiment is a procedure designed so that there is only one logical explanation for the results. Some types of experiments are fairly simple to design. Others may require ingenious problem solving.

Jerry Howard

Posing Questions

As a gardener harvested corn in her vegetable garden, she noticed that on one side of the garden the plants produced very few ears of corn. The gardener wondered, *Why didn't the plants on one side of the garden produce as much corn?*

An experiment may begin when someone like the gardener asks a specific question or wants to solve a particular problem. Sometimes the original question leads directly to an experiment, but often researchers need to restate the problem before they can design an appropriate experiment. The gardener's question about the corn, for example, is too broad to be tested by an experiment, since there are so many possible different answers. To narrow the topic, the gardener might think about several related questions: *Were the seeds the same on both sides of the garden? Was the sunlight the same? Is there something different about the soil?*

Formulating Hypotheses

In science, a question about an event is answered by developing a possible explanation called a **hypothesis**. The hypothesis may be developed after long thought and research or come to a scientist "in a flash." To be useful, a hypothesis must lead to predictions that can be tested.

In this case, the gardener decided to focus on the quality of the soil on each side of her garden. She did some tests and discovered that the soil had a lower pH on the side where the plants did not produce well. That led her to propose this hypothesis: *If the pH of the soil is too low, the plants will produce less corn.* The next step is to make a prediction based on the hypothesis, for example, *If the pH of the soil is increased using lime, the plants will yield more corn.* Notice that the prediction suggests the basic idea for an experiment.

Designing Experiments

A carefully designed experiment can test a prediction in a reliable way, ruling out other possible explanations. As scientists plan their experimental procedures, they pay particular attention to the variables that must be controlled and the procedures that must be defined.

The gardener decided to study three groups of plants:

Group 1—20 plants on the side of the garden with a low pH;

Group 2—20 plants on the side of the garden with a low pH, but with lime added; and

Group 3—20 plants on the side of the garden with a high pH.

Controlling Variables

As researchers design an experiment, they identify the **variables**, factors that can change. Some common variables include mass, volume, time, temperature, light, and the presence or absence of specific materials. An experiment involves three categories of variables. The factor that scientists purposely change is called the **manipulated variable**. The factor that may change because of the manipulated variable and that scientists want to observe is called the **responding variable**. And the factors that scientists purposely keep the same are called the **controlled variables**. Controlling variables helps make researchers confident that the observed changes in the responding variable are due to changes in the manipulated variable.

For the gardener, the manipulated variable is the pH of the soil. The responding variable is the number of ears of corn produced by the plants. Among the variables that must be controlled are the amount of sunlight received each day, the time of year when seeds are planted, and the amount of water the plants receive.

What Is a "Control Group"?

When you read about certain experiments, you may come across references to a control group (or "a control") and the experimental groups. All of the groups in an experiment are treated exactly the same except for the manipulated variable. In an experimental group, the manipulated variable is being changed. The control group is used as a standard of comparison. It may consist of objects that are not changed in any way or objects that are being treated in the usual way. For example, in the gardener's experiment, Group 1 is the control group, because for these plants nothing is done to change the low pH of the soil.

Forming Operational Definitions

In an experiment, it is often necessary to define one or more variables explicitly so that any researcher could measure or control the variable in exactly the same way. An **operational definition** describes how a particular variable is to be measured or how a term is to be defined. In this context, the term *operational* means "describing what to do."

The gardener, for example, has to decide exactly how much lime to add to the soil. Can lime be added after the seeds are planted or only before planting? At what pH should no more lime be added to the soil? In this case, the gardener decided to add lime only before planting, and to add enough lime to make the pH equal in Groups 2 and 3.

Analyzing Data

The observations and measurements that are made in an experiment are called **data**. Scientists customarily record data in an orderly way. When an experiment is done, the researcher analyzes the data for trends or patterns, often by doing calculations or making graphs, to determine whether the results support the hypothesis.

For example, the gardener regularly measured and recorded data such as the soil moisture, daily sunlight, and pH of the soil. She found that the soil pH in Groups 2 and 3 started the same, but after two months the soil pH for Group 3 was a little higher than the soil pH for Group 2.

After harvesting the corn, the gardener recorded the numbers of ears of corn produced by each plant. She totaled the number of ears for each group. Her results were the following.

Group 1: 67 ears of corn
Group 2: 102 ears of corn
Group 3: 126 ears of corn

The overall trend was clear: The gardener's prediction was correct.

Drawing Conclusions

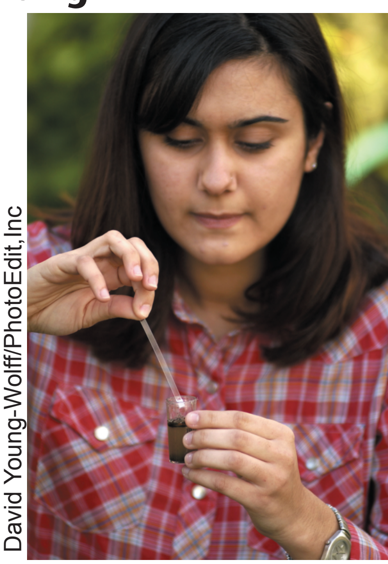
Based on whether the results confirm or refute the hypothesis, researchers make a final statement that summarizes the experiment. That final statement is called the **conclusion**. For example, the gardener's conclusion was, *Adding lime to soil with a low pH will improve the production of corn plants.*

Communicating Results

When an experiment has been completed, one or more events may follow. Researchers may repeat the experiment to verify the results. They may publish the experiment so that others can evaluate and replicate their procedures. They may compare their conclusion with the discoveries made by other scientists. And they may raise new questions that lead to new experiments. For example, *Why does the pH level decrease over time when soil is treated with lime?*

Evaluating and Revising

Scientists must be flexible about the conclusions drawn from an experiment. Further research may help confirm the results of the experiment or make it necessary to revise the initial conclusions. For example, a new experiment may show that lime can be effective only when certain microbes are present in the soil. Scientists continuously evaluate and revise experiments based on the findings in new research.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