1.2 Building Scientific Knowledge

Observation and Inference

From an early age, you have relied on experience in order to understand your environment. Babies and young children are "natural scientists" (**Figure 1**). They acquire understanding of their world through exploration and experimentation. For example, if you place a baby in a highchair and put different objects on the highchair tray, the baby will likely drop the objects onto the floor in rapid succession, focusing intently on where the objects fall. If you pick up the objects from the floor and put them on the highchair tray again, the baby will probably repeat the same actions.

The baby is not trying to annoy you, but to learn more about the objects through experimentation. Do the objects fall in the same spot? Do they make the same noise when they fall? Through **observation** and experience, the baby mentally collects information about the objects and then tries to make sense of the observations. The baby may collect additional information about the objects by tasting, touching, or shaking the objects. Scientists take a similar approach. They gather data through repeated experimentation and observation in order to test theories and hypotheses.

observation a statement that is based on what you see, hear, taste, touch, and smell

To understand the universe, scientists need to do more than simply observe it. Scientists need to go one step further and *infer* knowledge from their observations. An **inference** is a judgment or opinion that is based on direct observation. As you learned in "Getting Started," scientists know that large quantities of the mineral olivine exist on Mars. Given that olivine is easily eroded by water and that it is present in large quantities on Mars, some scientists infer that the frozen water on Mars may have always existed in a solid state.

inference a judgment or opinion that is based on observations and/or conclusions from testing

Figure 1
Babies are natural experimenters. They test the parameters of the environment around them in order to gain understanding.

Observation and inference are integral components of qualitative analysis. When trying to identify a sample of matter, scientists first *observe* the sample. Then they *infer* its identity based on their observations, by comparing their observations to characteristics of known matter. When you identified the mystery powder in section 1.1, you made an inference based on your observations of the physical and chemical properties of the other powders you tested.

TRY THIS activity — The Burning Candle

In many situations, it is important to understand the difference between an observation and an inference. For example, a police officer who is collecting data from a crime scene must provide statements based on observations only.

Materials: candle, match, pencil, paper, watch glass, ruler

1. Obtain a candle, match, and watch glass from your teacher.
2. Light the candle, and drip some of the wax onto the watch glass. Place the candle upright in the hot wax in order to secure it.
3. Observe the candle for 3 to 5 min.

A flickering candle can trigger a migraine or an epileptic seizure. Do not do this activity if you have either condition.

(a) Write down as many statements about the burning candle as you can think of.

(b) Divide the statements into two categories: inferences and observations.

(c) Compare the number of observations you made with the number of inferences.

(d) Provide one example of an observation and one example of an inference that could be stated by each of the following people:

(i) a nurse examining a patient with a high fever

(ii) a firefighter sifting through the debris of a recently extinguished fire

(iii) a chef tasting a new recipe

Empirical Knowledge and Theoretical Knowledge

Scientific knowledge is acquired through observation and inference. Information that is gathered by the *senses* or by the *extended senses* (using scientific equipment) is called **empirical knowledge**. Empirical knowledge *describes* what is being observed. For example, scientists have observed that when a thermometer placed in boiling water reads 100°C, the water changes state from liquid to gas (vapour). **Theoretical knowledge** attempts to *explain* how or why something occurs. To explain what happens when water boils, scientists use the *kinetic molecular theory* (**Figure 2**, on the next page). According to this theory, water molecules, clinging to each other by weak bonds in the liquid state, absorb energy when heated. When the temperature reaches 100°C, the water molecules have absorbed enough energy to overcome the weak bonds, and they enter the gaseous state. A **theory** is an explanation of a large number of related observations.

empirical knowledge knowledge coming directly from observations

theoretical knowledge knowledge based on ideas that are created to explain observations

theory an explanation of a large number of related observations

Figure 2
A vibrating box containing marbles is a physical model that represents the motion of particles, as described by the kinetic molecular theory of gases. (You will learn more about this theory in Unit 4.)

model a representation of a theoretical concept

Models

Once scientists have developed a theory, they must communicate it. A model is an effective way to communicate a theory or idea. An architect may construct a model of a building to present the design to a client. The globe in geography class is a physical model of the planet Earth. In science, a **model** is a restricted representation of a theory. A model can change over time as new information is added. For example, in the second century A.D., an Alexandrian astonomer and geographer named Ptolemy put forth the theory that Earth is at the centre of the universe (the geocentric model). In the sixteenth century, based on many years of extensive observations by himself and others, Nicolaus Copernicus, a Polish astronomer, presented his theory that Earth and the other planets revolve around the Sun (the heliocentric model).

Models are used not only to visualize a theory, but also to suggest ways to test the theory. If a theory fails to correctly predict new observations, it may need to be changed, along with the model.

In the next few sections, you will examine the evolution of the model of the *atom*.

Section 1.2 Questions

Understanding Concepts

1. Classify each of the following statements as either an inference or an observation:
   (a) The wood does not burn because it is wet.
   (b) The boiling point of methanol is 67.5°C.
   (c) The light that a glow stick emits can be prolonged if the glow stick is placed in a fridge.
   (d) The temperature of a metal increased due to an increase in the vibrations of the atoms within it.
   (e) There is 125 mL of water in the flask.
2. "Theories cannot be proven; they can only be supported with experimental evidence." Comment on this statement.
3. Explain how models are useful for conveying a theory or idea.

Making Connections

4. Using a concept map, illustrate how the following terms are interconnected: empirical knowledge, theoretical knowledge, inference, observation, theory.
5. In a court of law, responses from witnesses who state opinions are often struck from the record. Give reasons why a lawyer may want a witness to make statements based on observations rather than inferences.
6. Qualitative chemical analysis involves identifying a substance through diagnostic tests. Diagnostic tests are based on physical and chemical properties of substances. Is qualitative analysis empirical or theoretical? Give reasons for your answer.