Chapter 2

The Scientific Process

Inquiry

On August 21, 2003, on a specially built hill in Irvine, California, six adults climbed into cars with no motors and rolled downhill. In the Extreme Gravity Race, the cars reached speeds of up to 60 miles per hour as they raced down the hill using nothing but gravity for energy. The six cars represented six fiercely competitive design and engineering teams. The race featured teams from five different automakers. Each team had created the slipperiest low-friction car they could, using carbon fiber, titanium, and many other high-tech materials.

How did the cars reach such high speeds using nothing but gravity? How did each team design its car so that it would be as fast as possible? Answers to these questions involve experiments and variables. Read on, and you will find out how engineers learn to make things better, faster, and more efficient!

Key Questions

- ✔ *What does "learning by inquiry" mean?*
- ✔ *How do you design a good scientific experiment?*
- ✔ *How are science and engineering similar and how are they different?*

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2.1 Inquiry and the Scientific Method

Scientists believe the universe follows a set of rules called **natural laws**. Everything that happens obeys the same natural laws. Unfortunately, the natural laws are not written down nor are we born knowing them. *The primary goal of science is to discover what the natural laws are*. Over time, we have found the most reliable way to discover natural laws is through *scientific inquiry*.

What *inquiry* means

Inquiry is learning through questions

Learning by asking questions is called **inquiry** (Figure 2.1). Inquiry resembles a crime investigation with a mystery to solve. Something illegal happened and the detective must figure out who did it. Solving the mystery means accurately describing who did what, when they did it, and how. The problem is that the detective never actually *saw* what happened. The detective must **deduce** what happened in the past from information collected in the present.

Searching for evidence

In the process of inquiry, the detective asks lots of questions related to the mystery. The detective searches for evidence and clues that help answer the questions. Eventually, the detective comes up with a *theory* about what happened. The theory is a description of what must have occurred in the crime, down to the smallest details.

How do you know you have learned the truth?

At first, the detective's theory is only one possible explanation among several of what might have happened. The detective must have evidence to back up the theory. To be accepted, a theory must pass three demanding tests. First, it must be supported by enough evidence. Second, there cannot be even a *single* piece of evidence that contradicts the theory. Third, the theory must be unique, because if two theories both fit the facts equally well, you cannot tell which is correct. When the detective arrives at a theory that passes all three tests, he believes he has "solved" the mystery by using the process of inquiry.

VOCABULARY

natural law - a theory that has been tested many times without any contradictions.

inquiry - a process of learning that starts with asking questions and proceeds by seeking the answers to the questions.

deduce - to figure something out from known facts using logical thinking.

Figure 2.1: *The steps in learning through inquiry.*

Scientific evidence

What counts as scientific evidence?

In science, the only way to know if you are right is to test your idea against real evidence. But, what types of evidence qualify as *scientific* evidence? Do feelings or opinions count as scientific evidence? Does what other people think qualify as scientific evidence? The answer to both questions is no. Because evidence is so important in science, there are exacting rules defining what counts as scientific evidence.

An example of scientific evidence

Scientific evidence might include numbers, tables, graphs, words, pictures, sound recordings, or other information. The important thing is that the evidence accurately describes what happens in the real world (Figure 2.2). Scientific evidence might be collected without doing experiments in a laboratory. For example, Galileo used his telescope to look at the Moon. He recorded what he saw by sketching in his notebook. Galileo's sketches are considered scientific evidence.

When is evidence considered scientific?

Scientific evidence must be objective and repeatable. **Objective** means the evidence should describe *only what actually happened* as exactly as possible. **Repeatable** means that others who look the same way at the same thing will observe the same results. Galileo's sketches describe in detail what he actually saw through the telescope. That means the sketches are *objective*. Others who looked through his telescope saw the same thing. That makes the sketches *repeatable*. Galileo's sketches are good scientific evidence because they are both objective and repeatable. Galileo's sketches helped convince people that the Moon was actually a world like Earth with mountains and valleys. This was not what people believed in Galileo's time.

Communicating scientific evidence with exact definitions

It is important that scientific evidence be clear, with no room for confusion or misunderstanding. For this reason, scientists define concepts like force and weight very clearly. Usually, the scientific definition is similar to the everyday meaning of the word, but more exact. For example, when you talk about your weight in everyday terms, you're talking about the number of pounds that your body weighs. In science, your weight is the force of gravity pulling on the mass of your body.

VOCABULARY

objective - describes evidence that documents only what actually happened as exactly as possible.

repeatable - describes evidence that can be seen independently by others if they repeat the same experiment or observation in the same way.

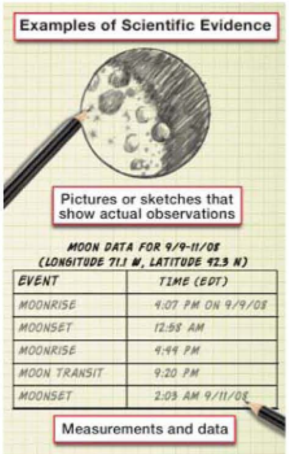

Figure 2.2: *Some examples of scientific evidence.*

Scientific theories

How theories are related to natural laws

A scientific **theory** is a human attempt to describe a natural law. For example, if you leave a hot cup of coffee on the table, eventually it will cool down. Why? There must be some natural law that explains what causes the coffee to cool. A good place to start looking for the law is by asking what it is about the coffee that makes it hot. Whatever quality that creates "hot" must go away or weaken as the coffee gets cold (Figure 2.3). The question of what causes hot and cold puzzled people for a long time.

The theory of caloric

Before 1843, scientists believed (a theory) that heat was a kind of fluid (like water) that flowed from hotter objects to colder objects. They called this fluid *caloric*. People thought hot objects had more caloric than cold objects. When a hot object touched a cold object, they believed the caloric flowed between the objects until the temperatures were the same.

Testing the theory

The caloric theory explained what people knew at the time. However, a big problem arose when people learned to measure weight accurately. Suppose caloric really does flow from a hot object to a cold object. That means an object should weigh more when it's hot than it does when it's cold. Experiments showed this was not true. Precise measurements showed that objects have the same weight, whether hot or cold. The caloric theory was soon abandoned because it could not explain this new evidence.

How theories are tested against evidence

Scientists are always testing theories against new experiments and new evidence. One of two things can happen when new evidence is found.

1. The current theory correctly explains the new evidence. This gives us confidence that the current theory is the correct one.

OR

2. The current theory does *not* explain the new evidence. This means there is a new (or improved) theory waiting to be discovered that can explain the new evidence (while continuing to validate the existing evidence).

VOCABULARY

theory - a scientific explanation supported by a lot of evidence collected over a long period of time.

Figure 2.3: *A question that might begin inquiry into what "heat" really is.*

CHALLENGE

Humans understood much less about science 1,000 years ago. That doesn't mean that people didn't know about things like temperature. They knew the difference between hot and cold, but they didn't know the *scientific reason* for why things were hot or cold. In Aristotle's time, scientific thinkers were convinced that Earth was the center of the universe. How did Copernicus and Kepler convince people to change their minds? Do some research on how Copernicus and Kepler contributed to our scientific understanding of Earth's place in the universe.

Hypotheses

The hypothesis Based on observations and evidence, a good detective evaluates many different theories for what might have happened. Each different theory is then compared with the evidence. The same is true in science, except that the word *theory* is reserved for a single explanation supported by lots of evidence collected over a long period of time. Instead of *theory*, scientists use the word **hypothesis** to describe a possible explanation for a scientific mystery.

Theories start out as hypotheses Theories in science start out as hypotheses. The old explanation that heat was the fluid caloric was an incorrect hypothesis, one of many leading up to the modern theory of heat. The first hypothesis that heat is a form of energy was made by a German doctor, Julius Mayer, in 1842, and confirmed by experiments done by James Joule in 1843. Energy has no weight, so Mayer's hypothesis explained why an object's weight remained unchanged whether it was hot or cold. After many experiments, Mayer's hypothesis (that heat was a form of energy) became the *theory* of heat that we accept today (Figure 2.4).

Hypotheses must be testable to be scientific A scientific hypothesis must be testable. That means it must be possible to collect evidence that proves whether the hypothesis is true or false. This requirement means *not all hypotheses* can be considered by science. For instance, it has been believed at times that creatures are alive because of an undetectable "life force." This is not a scientific hypothesis because there is no way to test it. If the "life force" is undetectable, that means no evidence can be collected that would prove whether it exists or not. Science restricts itself to only those ideas that may be proved or disproved by actual evidence.

VOCABULARY

hypothesis - a possible explanation that can be tested by comparison with scientific evidence.

Figure 2.4: *A hot cup of coffee has more heat energy than a cold cup of coffee. As coffee cools, its heat energy is transferred to the air in the room. As a result, the air is warmed.*

The scientific method

VOCABULARY

scientific method - a process of learning that begins with a hypothesis and proceeds to prove or change the hypothesis by comparing it with scientific evidence.

Learning by chance In their early years, children learn about the world by trial and error. Imagine a small child trying to open a jar. She will try what she knows: biting the lid, pulling on it, shaking the jar, dropping it… until, by chance, she twists the lid. It comes off. She puts it back and tries twisting it again—and the lid comes off again. The child learns by trying many different things and then *remembering what works*.

Learning by the scientific method It takes a long time to learn by randomly trying everything. What's worse, you can never be sure you tried *everything*. The **scientific method** is a much more dependable way to learn.

The Scientific Method

1. Scientists observe nature, then develop or revise hypotheses about how things work.
2. The hypotheses are tested against evidence collected from observations and experiments.
3. Any hypothesis that correctly accounts for all of the evidence from the observations and experiments is a potentially correct theory.
4. A theory is continually tested by collecting new and different evidence. Even one single piece of evidence that does not agree with a theory will force scientists to return to step one.

Why the scientific method works The scientific method is the underlying logic of science. It is a careful and cautious way to build an evidence-based understanding of our natural world. Each theory is continually tested against the results of observations and experiments. Such testing leads to continued development and refinement of theories to explain more and more different things. The way people came to understand the solar system is a good example of how new evidence leads to new and better theories (Figure 2.5).

Early civilizations thought Earth was covered by a dome on which the Sun, stars, and planets moved.

During the Middle Ages, people thought the Sun, stars, and planets circled Earth which sat in the center.

Today we know Earth and planets orbit around the Sun, and the stars are very far away.

Figure 2.5: *Three different models for Earth and the solar system that were believed at different times in history.*

Section 2.1 Review

1. Which of the following is an example of deduction?
   a. Hector calls the weather service to find out if the temperature outside is below freezing.
   b. Caroline looks out the window and concludes that the temperature is below freezing because she sees that the puddles in her neighbor's driveway are frozen.
2. Describe the relationship between a hypothesis, a theory, and a natural law.
3. To be correct, a scientific theory must be everything **except**
   a. supported by every part of a large collection of evidence
   b. considered to be unchangeable even if new scientific evidence disproves it
   c. testable by comparison with scientific evidence
   d. an explanation of something that actually occurs within the natural world or within technology
4. Julie, a third grade student, believes that the Moon disappears on certain days every month. Explain why the following information is or is not scientific evidence that can be used to evaluate Julie's hypothesis.
   a. Julie sometimes cannot see the Moon all night even though the sky is clear.
   b. Anne, Julie's older sister, thinks the phases of the Moon are caused by the Moon's position in its orbit around Earth.
5. When describing scientific evidence, what is the meaning of the word *repeatable*?
6. Which of the following is an example of learning through inquiry?
   a. Miguel is told that hot objects, like a cup of coffee, cool off when left on the table in a cooler room.
   b. Erik wonders what happens to hot objects if you remove them from the stove. He puts a thermometer in a pot of boiling water and observes that the water cools off once it's removed from the heat source.

STUDY SKILLS

Keep Your Eyes and Ears Open

A great many discoveries were made almost by accident! For example, paper used to be made of cotton or linen, which are costly plant fibers. Inventors searched for a less expensive way to make paper. In 1719, French scientist and inventor Rene de Reaumer was walking in the woods when he noticed that wasp nests were made from something a lot like paper! How did the wasps do it? In 1840, Friedrich Keller made the first all-wood paper and today nearly all paper is made from wood. Reaumer's curiosity and alert eyes lead directly to the paper we use today.