# 1–2 The Scientific Method

**Guide For Reading**

- What are the steps in the scientific method?
- What is the difference between a control setup and an experimental setup?
- What are the basic units of length, mass, volume, and temperature in the metric system?

The simplest definition of the **scientific method** was offered by biologist Claude Villee. He called it "Organized common sense." That is exactly what science should be. **In practice, the scientific method consists of several steps:**

- **Observing and stating a problem**
- **Forming a hypothesis**
- **Testing the hypothesis**
- **Recording and analyzing data**
- **Forming a conclusion**
- **Replicating the work**

To the true scientist, however, the scientific method is more a frame of mind—a frame of mind that involves curiosity. For without curiosity about nature, there would be no interest in why the sun appears to rise and set, why the seasons change, or why a snake sheds its skin. Another important characteristic of the scientific spirit is the refusal to accept an explanation without evidence or proof. This "prove it!" attitude encourages scientists to investigate phenomena and to develop new explanations and ideas.

## Observing and Stating a Problem

The process of science starts with an observation. For example, we might notice that the leaves of maple trees turn bright red and yellow in autumn. As curious scientists, we would then be interested in discovering why this color change takes place.

***Figure 1–4*** *The changing colors of the leaves in Vermont is an event to which people travel from all over the country to enjoy. What hypothesis could you suggest to explain why the leaves of many trees change color in autumn?*

![Quick Lab]

**Quick Lab**

To reinforce the **Main Idea** of the scientific method, perform the Quick Lab activity called Solving a Mystery on p. 1080.

## Forming a Hypothesis

We proceed to gather information that helps us generate a **hypothesis**. A hypothesis is a possible explanation, a preliminary conclusion, or even a guess about some event in nature. For example, we can observe that maple leaves change color when the air gets colder. We might then hypothesize that color changes in maples are related to changes in temperature.

## Testing the Hypothesis

Next we must test our hypothesis. Some hypotheses may be tested simply through further observation. As you will discover in Chapter 13, Charles Darwin spent most of his life in the field observing nature to test his hypotheses about evolution. Most hypotheses, however, must be tested by experiments. The "autumn leaves" hypothesis falls into this category.

Our observations indicate that leaves change color in the autumn. And our hypothesis is that the color change is related to changes in temperature. We must now perform a test to find out if this is a correct explanation. One experiment we might do is to take a small maple tree growing in a pot and place it in a growth chamber during the month of July. We would lower the temperature to typical autumn levels, about 14°C during the daytime and 3°C at night. If our hypothesis is correct, we might see the leaves begin to change color almost immediately.

Suppose we ran this experiment and the leaves did change color. Would we know for certain that changes in temperature alone were responsible for the color change? After all, there are many differences between the tree in our experiment and a tree in the woods. Did the leaves on our tree turn red because the tree was planted in a small pot? Or because the light inside the growth chamber was different from natural light?

These uncertainties point out the need for a more complicated experiment using at least two trees. We should choose two similar trees and pots of the same size, water the trees at the same time, and place them in identical chambers. We should then conduct an experiment in which one chamber is kept at normal summer temperatures while the other chamber is cooled to autumn temperatures.

Why must we go to the trouble of observing a second tree? This two-part test represents what is called a controlled experiment. Controlled experiments allow researchers to isolate and test the effects of a single factor, or experimental **variable**. In this case, the treatment of the first tree serves as our **control setup** by testing the effects of the pot and growth chamber. The treatment of the second tree, our **experimental setup**, is identical to the control setup in every respect except one—the variable of temperature. See Figure 1-5. Now if we observe a difference between the experimental setup and the control setup, we can be more certain that it is due to the lower temperatures in the experimental chamber.

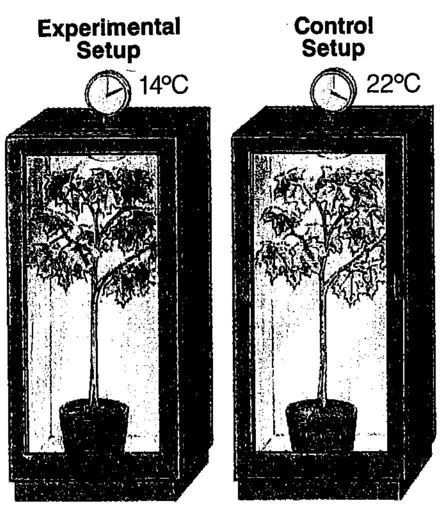


***Figure 1–5*** *Whenever possible, an experiment should have both a control setup and an experimental setup. Which part of the experiment contains the variable? What is the variable in this experiment?*

## Recording and Analyzing Data

If we were actually to perform this experiment, we would keep careful records of observations and information, or **data.** In this case, such data might include the time it took for each leaf to change color, the total number of leaves on each tree that changed color or fell off, and so on. We might arrange our data in the form of tables and graphs, such as those shown in Figure 1-6. You can see why researchers use these visual representations of experimental data to analyze their results.

| EXPERIMENTAL SETUP: Autumn Temperatures | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 |
| Number of Green Leaves | 50 | 50 | 50 | 49 | 49 | 48 | 48 | 48 | 48 | 47 | 47 |

| CONTROL SETUP: Spring Temperatures | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 |
| Number of Green Leaves | 50 | 50 | 49 | 49 | 49 | 49 | 49 | 47 | 47 | 47 | 47 |

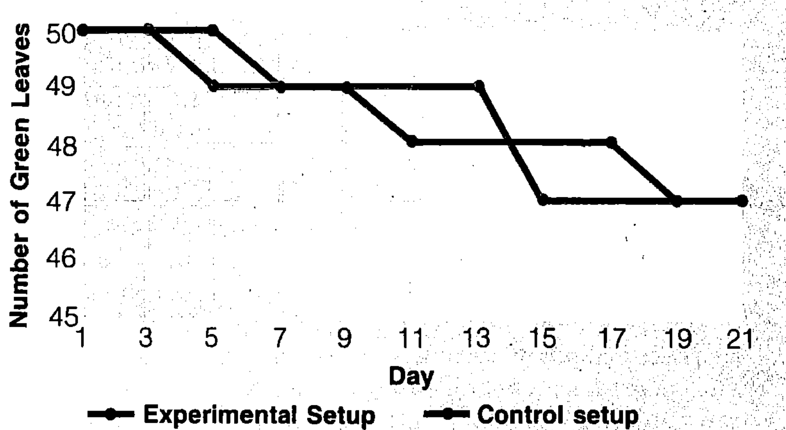


*__Figure 1-6__ Information gathered from an experiment is usually organized in data tables (top). Then the data may be graphed in order to provide a visual representation that is easy to interpret (bottom). Using the data tables and the graph, what conclusions can you reach about the autumn leaves hypothesis?*

## Forming a Conclusion

If we find that the leaves on our experimental tree change color and those on the control tree do not, we may decide that we have confirmed our original hypothesis: Cold temperatures cause leaves to change color. If the leaves of neither tree change color or if the leaves of both trees change color, we might reject the hypothesis as wrong and start all over with a new idea. This is often the case in science because many guesses about the natural world prove incorrect. But this is also the way science advances, for it points the way to further experiments. If the leaves on neither tree change color, for example, it is possible that temperature alone is not responsible. Perhaps trees also respond to changes in the length of day, decreases in rainfall, or the action of strong winds. These new hypotheses suggest additional experiments that expand our understanding.

Although such experiments are probably impossible for you to perform yourself, scientists have been able to do them and have arrived at an answer to our original hypothesis: Do the colder temperatures of autumn cause a color change in the leaves of maple trees? If you have examined the data in Figure 1-6, you know part of their conclusion: Colder temperatures alone do not cause the color change. Scientists now know that colder temperatures combined with a change in the length of day both play a role in the color change in maple leaves. In addition, many scientists believe that a biological clock within the maple tree also plays a role. But how does this biological clock work? And what chemical triggers the clock? These are questions that as yet remain unanswered. If you should choose to pursue biology as a career, perhaps you will consider these questions once again.

## Replicating the Work

The best scientific experiments can be replicated, or reproduced. In other words, it must be possible for either the original experimenter or other researchers to duplicate, or reproduce, the experimental results. Reproducibility in science takes many forms. We might want to replicate the experiment ourselves several times. Or we might want to put several trees in each growth chamber. Such actions would assure us that our results were not due to chance.

Another form of reproducibility is the replication of work by others. If interesting results come from an experiment, a researcher will publish a report of the work in a scientific journal. The report must contain enough detail so that other scientists can copy the experiment precisely to see if the same results continue to occur.

## Hypotheses and Theories

When a hypothesis is tested and confirmed often enough that it is unlikely to be disproved by future tests, it may become worthy of being called a **theory**. In scientific usage, the word theory means a great deal more than it does in common speech. Scientific theories are not just hunches or hypotheses. They are powerful, time-tested concepts that make useful and dependable predictions about the natural world.

## The Scientific Method—An Everyday Experience

Because many experiments discussed in this book were performed by people called scientists, you might think that science is a special process used only by certain people and useful only under special circumstances. That is not true at all. We all use the scientific method every day!

Let's suppose, for example, that a car will not start. A mechanic will form and test hypotheses about the problem: Perhaps the battery is dead. One experiment would be to crank the starter to see what happens. If the starter motor works but the car still doesn't turn over, it could be that the car is out of gas. A glance at the fuel gauge would test that idea. Again and again, the mechanic would apply the scientific method until the problem is solved. The same technique can find a fault in an electrical circuit or balance a load of laundry in a washing machine. Remember, science is just organized common sense.