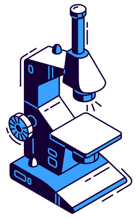
Introduction

Many of us have had unanswered questions about our environment—why…? how…? when…? Some of us have gone to find answers. Most of us, however, must depend on more qualified individuals for answers.

Most often, those qualified individuals are scientists, investigators in the field of science. They specialize in finding answers in an efficient and organized manner.



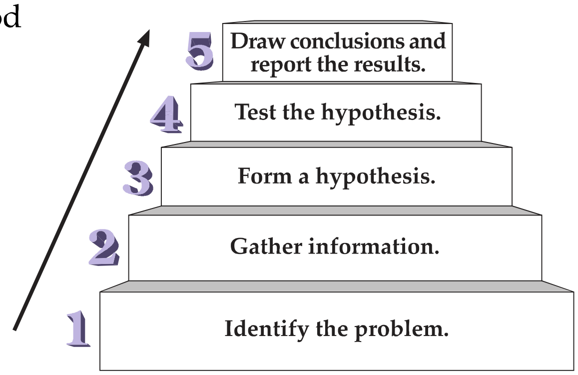
Scientists—investigators in the field of science.

To investigate efficiently and in an organized way, scientists must use a certain method. This method is called the **scientific method**, a way of solving problems using specific steps. Scientists must also be careful to follow safety rules when they conduct **experiments** in the **laboratory**. Scientists follow *laboratory* rules to protect the results of their *experiments* and prevent accidents.

Steps of the Scientific Method

Have you ever observed something in nature and wondered what it is and how it works? If so, you have that in common with scientists. Scientists wonder about nature. They ask questions and design experiments to find the answers to their questions.

Whenever scientists have questions or problems, they use a certain method called the *scientific method* to find answers. It is a way of solving problems using five specific steps: identifying the problem, gathering information, forming a **hypothesis**, testing the *hypothesis*, and drawing **conclusions** and reporting the results. The method allows scientists to look at a specific problem and develop some solutions. Using the scientific method, scientists can look at each possible solution to determine if it is correct.



Steps of the Scientific Method

Step l: Identify the problem

The first step is to identify the problem and develop a question about it. The study of a problem always begins with a question. Scientists must know exactly what the question is so that they can decide how they want to go about finding an answer to it.

In a study about the origins of coquina, a stone made of broken shells found in Florida, scientists had only one question: How did coquina stone made from organisms that lived in the ocean come to be found miles away, far from the beaches and sea?

Step 2: Gather information

Then information is collected about the question. **Observations** are made and recorded. Careful *observations* are important in gathering information. Scientists observe everything they can about a scientific problem. By studying coquina in areas where it seemed unlikely they could have formed, scientist used many ways of collecting information to learn when and where the stone formed.

There are various ways to collect information. Some of the ways are listed below.

Ways to Collect Information

- reading about what other scientists have done on the subject
- using the senses (sight, hearing, smell, touch, or taste) to make observations
- using scientific equipment, such as a telescope

Confirmed observations can become scientific **facts**. A *fact* is an idea that has been proven by experiments. Observations and facts are then recorded. This recorded information becomes **data**. Scientific facts, often in the form of numbers, are called *data*. Scientists must use logical reasoning to interpret their data.

Step 3: Form a hypothesis

Looking at the data gathered, scientists make a guess and suggest what may be the answer to the problem. This guess, which is based on observations, is called a *hypothesis*. A hypothesis is an idea or statement that explains the relationship of observed facts to each other. It is a tool for further study of the problem. A good hypothesis must include specific explanatory information so that it can be tested.

The idea that ocean levels change was a good hypothesis for several reasons. It explained why coquina rocks were found in dry areas as well as under the sea. It predicted that the level of the ocean would not remain constant over long periods of time and could change by either spreading or receding. Very importantly, this hypothesis could be tested.

A Good Hypothesis

- explains how observed facts relate to each other
- predicts new facts
- lends itself to testing; a hypothesis that cannot be tested is of no value

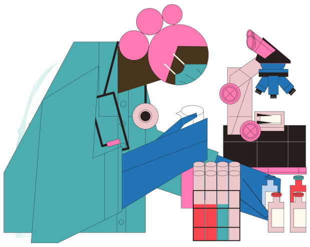
Step 4: Test the hypothesis

Scientists who proposed that the ocean levels could change would not have had a useful hypothesis if they had not found a way to test it. The test of their hypothesis was as important as the hypothesis itself.

Experimentation is the scientific testing of a hypothesis. It must be done in a careful manner. Scientists must repeat experiments many times before they accept the results. They must also test important factors under different conditions.

An experiment consists of two groups, the **experimental group** (which contains the variable being tested) and the **control group** (without the variable). The factor being tested in the experiment is the **variable factor**. A **controlled experiment** is one in which all the factors are the same except for the one being tested.

Scientists must carefully design their experiments to eliminate the possibility of bias (making their results fit their hypothesis). This is why several scientists will work together but separately on the same experiment to ensure accurate results. The experiment must also be repeated many times achieving the same results in order for *conclusions* to be made. A single result does not imply any conclusion.



Scientists must make careful and complete observations.

During and after experimentation, scientists must make careful and complete observations. Accurate records of the results must be made in the form of charts, graphs, or tables. Scientists use these charts, graphs, and tables to analyze their data. They look for similarities and differences between the results. Computer models or simulations can also be used to test collected data or a hypothesis. These analyses are used to help draw conclusions about their hypothesis.

Scientists developed ways to test their hypothesis that ocean levels change over time. They took precise measurements of the ocean levels.

Step 5: Draw conclusions and report the results

After the experiments are completed, conclusions are drawn. Scientists use the conclusions to reevaluate their hypothesis. They must decide if the conclusions confirm or contradict their hypothesis. An experiment does not always confirm a hypothesis. It may show that the hypothesis is partially or totally wrong. If the hypothesis is wrong, the scientist must go back and study the data and facts. The facts will be interpreted a different way. The scientist will develop a new hypothesis to be tested. Even if an experiment supports a hypothesis, the experiment may need to be repeated many times before the hypothesis can be confirmed.

Scientists who studied the question of how and where coquina stones formed learned a great deal. After years of measuring, their conclusions stated that oceans could change. Coquina that was found on dry land could have formed in the ocean.

Scientific Method in Action

Many scientific discoveries have been made by mistakes or by forming the wrong hypothesis. For example, penicillin was discovered as a mold that killed all of a researcher's bacteria. Scientists often ask other scientists from different disciplines to review their research and make suggestions for refining their hypothesis or figuring out why their hypothesis was not supported. Different conclusions may be reached by different teams of scientists working on the same problem. This difference of opinion helps the scientists reach a better understanding of the problem.

It is important to write down the results of experimentation and make them available for other scientists to use. The results may then be used to continue experimentation and to go on and make more new discoveries.

When a hypothesis has withstood the test of time, it is called a **theory**. An accepted *theory*, however, may change as new discoveries in science are made. At times scientists are unsure if old ideas are really true. They investigate these theories.

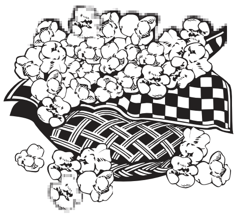
Galileo Galilei (1564–1642)

Scientists have been using the scientific method for about 400 years. It began with an Italian scientist named **Galileo Galilei** (1564–1642) who tested ideas about nature to explain the way things happen. Before *Galileo*, most people believed that heavier objects fell faster than lighter objects. No one bothered to test this idea. Instead, they accepted it as fact. Then Galileo decided to use the scientific method to investigate this hypothesis. Galileo found that objects fall at the same rate of acceleration regardless of their weight because gravity makes all objects accelerate at the same rate. However, gravity is not the only force at work. Objects are also affected by air resistance, the force air exerts on an object. This was a gigantic change in the way the world was seen and understood. Since that time, many other scientists have conducted investigations about gravity. They too have found that Galileo was right about the way things fall.

Even now, such major changes occasionally take place. It is more common, however, for the changes to be small. Whether big or small, changes take place because scientists all over the world share information. Often many scientists are working on the same problem. If the results among the different scientists are not the same, the hypothesis, approach, or methods may have to be changed. If a hypothesis has been tested many times and seems correct, it is called a *scientific theory*. After a theory has been tested and supported many times, it becomes a **scientific law**. In science, no theory or law is ever considered proven. Galileo showed us the reason for this, and, in fact, what Galileo said about gravity is still considered theory.

Scientific Testing

Suppose you wanted to find out if storing popcorn in the refrigerator would make a difference in the number of kernels that did not pop. You would need to also test popcorn stored at room temperature as a *control*, or the standard for comparison. All other conditions for both batches of popcorn would need to be the same: the same brand, same freshness, same storage time, and same method of preparation. Only one condition, the place of storage, should differ. All other factors are *constants* and cannot change.


Does storing popcorn in the refrigerator make a difference in the number of kernels that do not pop?

Scientists often test their hypotheses by conducting experiments under controlled conditions in the scientific laboratory. In some cases, conditions cannot be controlled. It would be hard to control conditions when investigating the way people behave or the way the trees in a large forest interact. In these cases, it may not be possible or ethical to conduct an experiment in a laboratory. Instead, scientists observe the widest range of natural behavior possible. Scientists may survey large numbers of people. They may record conditions in the forest for years and years. By doing this, scientists gather information that can be compared to laboratory results.

Another way to test theories about parts of the world is to use a **scale model**. Imagine you wanted to know how a building would behave during an earthquake. You couldn't create an actual earthquake in a laboratory. Instead, you might construct a small *scale model* of the building. Then you could shake it, simulating an earthquake. More and more, models using **computer simulations** are being made. One advantage of *computer simulations* is they permit scientists to test theories many times.

Sometimes theories are tested using **analogs**. *Analogs* are things that are similar but not exactly alike. Scientists use the similarities between analogs to learn. For example, you might want to know how a now extinct dinosaur flew. You might study how bats actually do fly. Bats are analogs to dinosaurs because both bats and dinosaurs flew without having feathers. There are some differences between the two, but the scientists study their similarities. With the right preparation, the results of this investigation would be a fairly accurate prediction and would show what it would take to make an extinct dinosaur fly. Try to think of an analog to a human. Could you study the analog to learn things about humans? Whether using analogs, computer simulations, or scale models, scientists work to be sure that their results are generally accurate.

Computers and Science

Computers have become very important in scientific studies. Some experiments are performed entirely by the computer. Scientists can develop computer models or simulations to test collected data or a hypothesis. These computer simulations allow scientists to perform complicated mathematical computations more quickly and reliably. Supercomputers can perform billions of calculations per second. Simulations are also used when experimenting may be very dangerous. Computer models help scientists refine their hypotheses and determine the type of information to be collected. Computers have helped speed up the scientific process. They allow scientists to simulate past events.

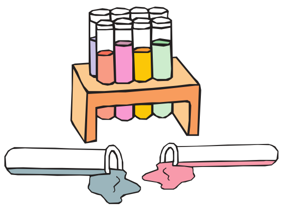
Computers have become very important in scientific studies.

With computers, scientists can share information and collaborate with others doing similar research. Computers also allow teams of scientists from different disciplines to review or duplicate research even if they are not on the same continent. The Internet was originally developed by the Department of Defense as a means of sharing and transmitting such research data quickly. Now we use the Internet to research current scientific discoveries, to ask scientists questions about their research, or to collect data for laboratory experiments or simulations. The Internet has helped the scientific community share current information. It is a great resource for up-to-date information. As with all other resources, however, information from the Internet must be carefully reviewed to determine its accuracy and reliability.

Laboratory Safety Rules

The school science laboratory can and should be a safe place in which to explore interesting and challenging activities. There is, however, one factor that is most important—and that is *safety*!

The rules and procedures on the following page should be followed at *all* times in order to make the science laboratory a safe place.



Make the science laboratory a safe place.

Safety Guidelines

1. Read and follow all directions while working in the laboratory.
2. Wear protective gear, such as aprons, at all times. Wear goggles when working with dangerous or hot chemicals, or any time your teacher instructs you to do so.
3. NEVER taste or directly inhale chemicals. Test the smell of a substance by *wafting* or fanning some of the odor to your nose with your hand. Your teacher can show you how.
4. DO NOT bring food or drink into the lab.
5. Wash hands thoroughly after each lab.
6. DO NOT rub eyes or put hands in mouth.
7. Dress in a way that helps you work safely and efficiently in the lab. Tie your hair back. Wear cotton—it doesn't catch fire as easily as nylon or polyester. Always keep your shoes on while in the lab. Roll up long or loose sleeves.
8. DO NOT look directly down into the mouth of a filled test tube. DO NOT point the mouth of a filled test tube at another student. Liquid can splash into eyes.
9. DO NOT perform any experiments unless the instructor is in the room.
10. Report ALL minor and major accidents to your instructor. Remain calm and do not alarm others by shouting or running.
11. Know the location of the safety shower, eye wash, and fire blanket. Know how to use these important pieces of safety equipment.
12. Turn off gas burners and the gas outlets when no one is using them. NEVER leave a lit burner unattended.
13. Use tongs or gloves to handle hot objects.
14. DO NOT look directly at the sun, with or without equipment, as it may damage your eyes.
15. Keep lab tables clean and neat to prevent accidents. Dispose of waste and used chemicals in appropriate location and manner according to teacher's instructions. Wipe all areas at the end of the lab.
16. MAKE SAFETY A HABIT!

Summary

The sharing of scientific information requires that scientists be able to obtain and report their findings in an efficient and consistent manner. When answering questions, scientists use the scientific method, a series of logical steps to solve problems.

1. Identify the problem.
2. Gather information.
3. Form a hypothesis.
4. Test the hypothesis.
5. Draw conclusions and report the results.

Scientists must handle materials properly. Just as scientists have specific rules and procedures for operating in the laboratory, we too must follow safety rules to make our experiences in the science laboratory safe and rewarding.