

1.2 The Scientific Methods

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Explain how the methods of science are used to make scientific discoveries
- Define a scientific model and describe examples of physical and mathematical models used in physics
- Compare and contrast hypothesis, theory, and law

Teacher Support

Teacher Support The learning objectives in this section will help your students master the following standards:

- (2) Scientific processes. The student uses a systematic approach to answer scientific laboratory and field investigative questions. The student is expected to:
 - (A) know the definition of science and understand that it has limitations, as specified in subsection (b)(2) of this section;
 - (B) know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories;
 - (C) know that scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well-established and highly-reliable explanations, but may be subject to change as new areas of science and new technologies are developed;
 - (D) distinguish between scientific hypotheses and scientific theories.

Section Key Terms

Teacher Support

Teacher Support [OL]Pre-assessment for this section could involve students sharing or writing down an anecdote about when they used the methods of science. Then, students could label their thought processes in their anecdote with the appropriate scientific methods. The class could also discuss their definitions of theory and law, both outside and within the context of science.

[OL]It should be noted and possibly mentioned that *a scientist*, as mentioned in this section, does not necessarily mean a trained scientist. It could be anyone using methods of science.

Scientific Methods

Scientists often plan and carry out investigations to answer questions about the universe around us. These investigations may lead to natural laws. Such laws are intrinsic to the universe, meaning that humans did not create them and cannot change them. We can only discover and understand them. Their discovery is a very human endeavor, with all the elements of mystery, imagination, struggle, triumph, and disappointment inherent in any creative effort. The cornerstone of discovering natural laws is observation. Science must describe the universe as it is, not as we imagine or wish it to be.

We all are curious to some extent. We look around, make generalizations, and try to understand what we see. For example, we look up and wonder whether one type of cloud signals an oncoming storm. As we become serious about exploring nature, we become more organized and formal in collecting and analyzing data. We attempt greater precision, perform controlled experiments (if we can), and write down ideas about how data may be organized. We then formulate models, theories, and laws based on the data we have collected, and communicate those results with others. This, in a nutshell, describes the scientific method that scientists employ to decide scientific issues on the basis of evidence from observation and experiment.

An investigation often begins with a scientist making an observation. The scientist observes a pattern or trend within the natural world. Observation may generate questions that the scientist wishes to answer. Next, the scientist may perform some research about the topic and devise a hypothesis. A hypothesis is a testable statement that describes how something in the natural world works. In essence, a hypothesis is an educated guess that explains something about an observation.

Teacher Support

Teacher Support [OL] An educated guess is used throughout this section in describing a hypothesis to combat the tendency to think of a theory as an educated guess.

Scientists may test the hypothesis by performing an experiment. During an experiment, the scientist collects data that will help them learn about the phenomenon they are studying. Then the scientists analyze the results of the experiment (that is, the data), often using statistical, mathematical, and/or graphical methods. From the data analysis, they draw conclusions. They may conclude that their experiment either supports or rejects their hypothesis. If the hypothesis is supported, the scientist usually goes on to test another hypothesis related to the first. If their hypothesis is rejected, they will often then test a

new and different hypothesis in their effort to learn more about whatever they are studying.

Scientific processes can be applied to many situations. Let's say that you try to turn on your car, but it will not start. You have just made an observation! You ask yourself, "Why won't my car start?" You can now use scientific processes to answer this question. First, you generate a hypothesis such as, "The car won't start because it has no gasoline in the gas tank." To test this hypothesis, you put gasoline in the car and try to start it again. If the car starts, then your hypothesis is supported by the experiment. If the car does not start, then your hypothesis is rejected. You will then need to think up a new hypothesis to test such as, "My car won't start because the fuel pump is broken." Hopefully, your investigations lead you to discover why the car won't start and enable you to fix it.

Modeling

A model is a representation of something that is often too difficult (or impossible) to study directly. Models can take the form of physical models, equations, computer programs, or simulations—computer graphics/animations. Models are tools that are especially useful in modern physics because they let us visualize phenomena that we normally cannot observe with our senses, such as very small objects or objects that move at high speeds. For example, we can understand the structure of an atom using models, despite the fact that no one has ever seen an atom with their own eyes. Models are always approximate, so they are simpler to consider than the real situation; the more complete a model is, the more complicated it must be. Models put the intangible or the extremely complex into human terms that we can visualize, discuss, and hypothesize about.

Scientific models are constructed based on the results of previous experiments. Even still, models often only describe a phenomenon partially or in a few limited situations. Some phenomena are so complex that they may be impossible to model them in their entirety, even using computers. An example is the electron cloud model of the atom in which electrons are moving around the atom's center in distinct clouds (Figure 1.12), that represent the likelihood of finding an electron in different places. This model helps us to visualize the structure of an atom. However, it does not show us exactly where an electron will be within its cloud at any one particular time.

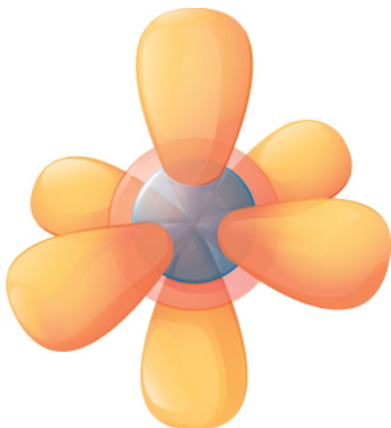


Figure 1.12 The electron cloud model of the atom predicts the geometry and shape of areas where different electrons may be found in an atom. However, it cannot indicate exactly where an electron will be at any one time.

As mentioned previously, physicists use a variety of models including equations, physical models, computer simulations, etc. For example, three-dimensional models are often commonly used in chemistry and physics to model molecules. Properties other than appearance or location are usually modelled using mathematics, where functions are used to show how these properties relate to one another. Processes such as the formation of a star or the planets, can also be modelled using computer simulations. Once a simulation is correctly programmed based on actual experimental data, the simulation can allow us to view processes that happened in the past or happen too quickly or slowly for us to observe directly. In addition, scientists can also run virtual experiments using computer-based models. In a model of planet formation, for example, the scientist could alter the amount or type of rocks present in space and see how it affects planet formation.

Scientists use models and experimental results to construct explanations of observations or design solutions to problems. For example, one way to make a car more fuel efficient is to reduce the friction or drag caused by air flowing around the moving car. This can be done by designing the body shape of the car to be more aerodynamic, such as by using rounded corners instead of sharp ones. Engineers can then construct physical models of the car body, place them in a wind tunnel, and examine the flow of air around the model. This can also be done mathematically in a computer simulation. The air flow pattern can be analyzed for regions smooth air flow and for eddies that indicate drag. The model of the car body may have to be altered slightly to produce the smoothest pattern of air flow (i.e., the least drag). The pattern with the least drag may be the solution to increasing fuel efficiency of the car. This solution might then be incorporated into the car design.

Snap Lab

Using Models and the Scientific Processes Be sure to secure loose items before opening the window or door.

In this activity, you will learn about scientific models by making a model of how air flows through your classroom or a room in your house.

- One room with at least one window or door that can be opened
- Piece of single-ply tissue paper
 1. Work with a group of four, as directed by your teacher. Close all of the windows and doors in the room you are working in. Your teacher may assign you a specific window or door to study.
 2. Before opening any windows or doors, draw a to-scale diagram of your room. First, measure the length and width of your room using the tape measure. Then, transform the measurement using a scale that could fit on your paper, such as 5 centimeters = 1 meter.
 3. Your teacher will assign you a specific window or door to study air flow. On your diagram, add arrows showing your hypothesis (before opening any windows or doors) of how air will flow through the room when your assigned window or door is opened. Use pencil so that you can easily make changes to your diagram.
 4. On your diagram, mark four locations where you would like to test air flow in your room. To test for airflow, hold a strip of single ply tissue paper between the thumb and index finger. Note the direction that the paper moves when exposed to the airflow. Then, for each location, predict which way the paper will move if your air flow diagram is correct.
 5. Now, each member of your group will stand in one of the four selected areas. Each member will test the airflow. Agree upon an approximate height at which everyone will hold their papers.
 6. When you teacher tells you to, open your assigned window and/or door. Each person should note the direction that their paper points immediately after the window or door was opened. Record your results on your diagram.
 7. Did the airflow test data support or refute the hypothetical model of air flow shown in your diagram? Why or why not? Correct your model based on your experimental evidence.
 8. With your group, discuss how accurate your model is. What limitations did it have? Write down the limitations that your group agreed upon.

Your diagram is a model, based on experimental evidence, of how air flows through the room. Could you use your model to predict how air would flow through a new window or door placed in a different location in the classroom? Make a new diagram that predicts the room's airflow with the addition of a new window or door. Add a short explanation that describes how.

- a. Yes, you could use your model to predict air flow through a new window. The earlier experiment of air flow would help you model the system more accurately.
- b. Yes, you could use your model to predict air flow through a new window. The earlier experiment of air flow is not useful for modeling the new system.
- c. No, you cannot model a system to predict the air flow through a new window. The earlier experiment of air flow would help you model the system more accurately.
- d. No, you cannot model a system to predict the air flow through a new window. The earlier experiment of air flow is not useful for modeling the new system.

Teacher Support

Teacher Support This Snap Lab! has students construct a model of how air flows in their classroom. Each group of four students will create a model of air flow in their classroom using a scale drawing of the room. Then, the groups will test the validity of their model by placing weathervanes that they have constructed around the room and opening a window or door. By observing the weather vanes, students will see how air actually flows through the room from a specific window or door. Students will then correct their model based on their experimental evidence. The following material list is given per group:

- One room with at least one window or door that can be opened (An optimal configuration would be one window or door per group.)
 - Several pieces of construction paper (at least four per group)
 - Strips of single ply tissue paper
 - One tape measure (long enough to measure the dimensions of the room)
 - Straws
 - Scissors
 - tape
1. Group size can vary depending on the number of windows/doors available and the number of students in the class.
 2. The room dimensions could be provided by the teacher. Also, students may need a brief introduction in how to make a drawing to scale.
 3. This is another opportunity to discuss controlled experiments in terms of why the students should hold the strips of tissue paper at the same height and in the same way. One student could also serve as a control and stand far away from the window/door or in another area that will not receive air flow from the window/door.
 4. You will probably need to coordinate this when multiple windows or doors are used. Only one window or door should be opened at a time for best results. Between openings, allow a short period (5 minutes) when all

windows and doors are closed, if possible.

Answers to the Grasp Check will vary, but the air flow in the new window or door should be based on what the students observed in their experiment.

Scientific Laws and Theories

A scientific law is a description of a pattern in nature that is true in all circumstances that have been studied. That is, physical laws are meant to be universal, meaning that they apply throughout the known universe. Laws are often also concise, whereas theories are more complicated. A law can be expressed in the form of a single sentence or mathematical equation. For example, Newton's second law of motion, which relates the motion of an object to the force applied (F), the mass of the object (m), and the object's acceleration (a), is simply stated using the equation

$$F = ma.$$

Scientific ideas and explanations that are true in many, but not all situations in the universe are usually called principles. An example is Pascal's principle, which explains properties of liquids, but not solids or gases. However, the distinction between laws and principles is sometimes not carefully made in science.

A theory is an explanation for patterns in nature that is supported by much scientific evidence and verified multiple times by multiple researchers. While many people confuse theories with educated guesses or hypotheses, theories have withstood more rigorous testing and verification than hypotheses.

Teacher Support

Teacher Support [OL] Explain to students that in informal, everyday English the word *theory* can be used to describe an idea that is possibly true but that has not been proven to be true. This use of the word *theory* often leads people to think that scientific theories are nothing more than educated guesses. This is not just a misconception among students, but among the general public as well.

As a closing idea about scientific processes, we want to point out that scientific laws and theories, even those that have been supported by experiments for centuries, can still be changed by new discoveries. This is especially true when new technologies emerge that allow us to observe things that were formerly unobservable. Imagine how viewing previously invisible objects with a microscope or viewing Earth for the first time from space may have instantly changed our scientific theories and laws! What discoveries still await us in the future? The constant retesting and perfecting of our scientific laws and theories allows our knowledge of nature to progress. For this reason, many scientists are reluctant to say that their studies *prove* anything. By saying *support* instead of *prove*, it keeps the door open for future discoveries, even if they won't occur for centuries or even millennia.

Teacher Support

Teacher Support [OL]With regard to scientists avoiding using the word *prove*, the general public knows that science has proven certain things such as that the heart pumps blood and the Earth is round. However, scientists should shy away from using *prove* because it is impossible to test every single instance and every set of conditions in a system to absolutely prove anything. Using *support* or similar terminology leaves the door open for further discovery.

Check Your Understanding

6.

Explain why scientists sometimes use a model rather than trying to analyze the behavior of the real system.

- a. Models are simpler to analyze.
- b. Models give more accurate results.
- c. Models provide more reliable predictions.
- d. Models do not require any computer calculations.

7.

Describe the difference between a question, generated through observation, and a hypothesis.

- a. They are the same.
- b. A hypothesis has been thoroughly tested and found to be true.
- c. A hypothesis is a tentative assumption based on what is already known.
- d. A hypothesis is a broad explanation firmly supported by evidence.

8.

What is a scientific model and how is it useful?

- a. A scientific model is a representation of something that can be easily studied directly. It is useful for studying things that can be easily analyzed by humans.
- b. A scientific model is a representation of something that is often too difficult to study directly. It is useful for studying a complex system or systems that humans cannot observe directly.
- c. A scientific model is a representation of scientific equipment. It is useful for studying working principles of scientific equipment.
- d. A scientific model is a representation of a laboratory where experiments are performed. It is useful for studying requirements needed inside the laboratory.

9.

Which of the following statements is correct about the hypothesis?

- a. The hypothesis must be validated by scientific experiments.

- b. The hypothesis must not include any physical quantity.
- c. The hypothesis must be a short and concise statement.
- d. The hypothesis must apply to all the situations in the universe.

10.

What is a scientific theory?

- a. A scientific theory is an explanation of natural phenomena that is supported by evidence.
- b. A scientific theory is an explanation of natural phenomena without the support of evidence.
- c. A scientific theory is an educated guess about the natural phenomena occurring in nature.
- d. A scientific theory is an uneducated guess about natural phenomena occurring in nature.

11.

Compare and contrast a hypothesis and a scientific theory.

- a. A hypothesis is an explanation of the natural world with experimental support, while a scientific theory is an educated guess about a natural phenomenon.
- b. A hypothesis is an educated guess about natural phenomenon, while a scientific theory is an explanation of natural world with experimental support.
- c. A hypothesis is experimental evidence of a natural phenomenon, while a scientific theory is an explanation of the natural world with experimental support.
- d. A hypothesis is an explanation of the natural world with experimental support, while a scientific theory is experimental evidence of a natural phenomenon.

Teacher Support

Teacher Support Use the Check Your Understanding questions to assess students' achievement of the section's learning objectives. If students are struggling with a specific objective, the Check Your Understanding will help identify which objective and direct students to the relevant content.