Scientific Concepts

Science can be defined as a body of knowledge that is continually being extended, refined, and revised based on new evidence. Scientific ideas can also be modeled through evidence-based investigations in order to better understand complex phenomena.

What is Science?

Science is a method of generating knowledge through consensus. The scientific method is designed to address questions about the material world in a way that other people can understand, follow, and repeat. But some questions cannot be answered by scientific research because they are not scientifically testable. For example, questions that involve intrinsic value, ethics, or morality cannot be answered by science.

Law, Hypothesis, or Theory?

There are many different types of statements that explain observations or phenomena in the natural world. Scientific statements are classified based on the type of information they explain.

Scientific facts are statements that are indisputable. Facts do not make generalizations. Accurate measurements are examples of scientific facts.

Scientific principles or **laws** are concise statements that explain a phenomenon that always occurs predictably under a specific set of circumstances. Most often, laws involve mathematical equations, such as the *ideal gas law equation (PV =nRT)*.

A **hypothesis** is a statement that provides a possible explanation to a specific phenomenon. It is based on observations and previous research. In order to be valid, a hypothesis must be testable. Only a statement that is subject to disproval, or falsification, can qualify as a scientific hypothesis. And if the evidence does not support the claim, a hypothesis can be rejected.

A **scientific theory** is a broad explanation of a set of related observations or events. Scientific theories often incorporate many interrelated hypotheses and laws, and they provide a general mechanism for how all of the different factors work together. Scientific theories must be able to explain past events as well as predict future occurrences or future observations. Therefore, theories can never be proven because there always exists a possibility, even if the probability is highly unlikely, that a future event will not conform to the theory.

Although theories must be supported by a great deal of evidence before they are accepted, even accepted theories can be challenged as new evidence is discovered. New evidence often surfaces with the invention of new technologies. At this point, theories can be modified to fit the new evidence, overturned, or even replaced by new theories. More often than not, however, the changes that take

place in scientific theories are small modifications of prior knowledge rather than major shifts in the overall scientific view of how the world works.

Science Asks Questions

It is the nature of science to question everything that is testable. Scientists always try to do the following:

- question claims that are made by people who are not experts in a specific field or claims that are based on vague attributions such as "Leading doctors say..."
- identify flaws of reasoning in arguments that are based on poorly defined research (e.g. facts mixed with opinions, conclusions based on insufficient evidence).
- question the value of arguments based on small samples of data, biased samples, or experiments that did not have a control.
- recognize that there may be more than one way to interpret a given set of data.

Scientists often publish the results of their experiments in scientific journals, so they can collaborate with other scientists and eliminate bias. Thus, accurate record keeping, data sharing, and replication of results are essential for maintaining the scientist's credibility with others in society.

When similar investigations give different results, scientists must determine if the differences are minor or more significant and if further experimentation is required. If new scientific results contradict elements of a scientific theory, the theory is only amended after many different scientists agree that the theory requires modification. Major shifts in scientific views very rarely occur, but minor modifications of prior knowledge are continually made based on new research.

Nature of Science

Science is not a static body of knowledge; it is a process that helps us understand how the natural world works. As technology increases our ability to answer questions, scientific knowledge is open to change as new evidence becomes available.

Scientific Knowledge

Scientific knowledge is gained through *observation* and *investigation*, but in order for new knowledge and methods to be accepted, the scientific investigations and explanations must meet certain criteria:

- They must be consistent with experimental and observational evidence about nature.
- They must be logical and respect the rules of evidence.
- They must be open to criticism.
- They must be clearly reported such that opportunities for further investigations are enhanced.

The Nature of Scientific Theories

Although scientific theories are based on extensive research, they are subject to change as new evidence becomes available, so theories are continually being tested, revised, and even occasionally discarded.

All current scientific theories, such as *atomic theory*, the *theory of evolution by natural selection*, *plate tectonic theory*, *germ theory*, and the *big bang theory*, are open to criticism and can be challenged as new evidence surfaces. More often than not, however, the changes made to scientific theories are often small modifications of prior knowledge rather than major shifts in the overall scientific view of how the world works.

For example, the following describes the major scientific developments in atomic theory.

- **c. 400 B.C.**

  The Greek philosopher Democritus proposed that matter is composed of relatively simple particles that are too small to be visible to the naked eye. These particles, which he called *atoma* (a Greek word meaning, "things that cannot be cut or divided"), could not be further broken down into smaller particles.

- **early 1800s**

  British scientist John Dalton proposes that atoms of different substances can be distinguished by their mass.

- **1897**

  British physicist Joseph Thomson performs an experiment that proves that atoms contain negatively charged particles-electrons.

- **1901**

  American researcher Robert Millikan experimented with drops of oil in order to calculate the mass of electrons.

- **1911**

  British chemist Ernest Rutherford proposed that an atom contained a nucleus, which was positively charged, dense, and very small. Rutherford is also credited with having discovered the proton in 1919.

- **1932**

  British physicist James Chadwick, building upon Rutherford's experiments, discovered that atomic nuclei contain neutrally charged particles-neutrons-in addition to protons.

Some scientific ideas are incomplete and require more research or more advanced technology to reach completion. For example, the invention of the microscope led to a deeper understanding of the basic units of life and the eventual development of *cell theory*.

Peer Review

After a scientific investigation is complete, scientists publish their results and methods in scientific journals so that other scientists can read about them. All articles submitted for publication in academic journals must first undergo peer review. During the process of **peer review**, fellow scientists working in the same field of study have their chance to voice any concerns about the experimental methods and results. Peer review and journal publication are used to reinforce the integrity of scientific investigations and reported data.

Ethics in Science

Professional scientists and engineers follow **ethical codes** that dictate what investigations and research they can perform. It is unethical for scientists to perform experiments that could harm human beings unless the subjects are voluntary and are fully knowledgeable of any possible consequences from the experiments. There are many laws that govern the use of humans in experiments. These laws must be stringently followed when conducting an experiment.