What is Science?[1]

Douglas L. Shrake[2], Lynn E. Elfner[3], William Hummon[4], Richard W. Janson[5], and Miles Free[6], The Ohio Academy of Science, 1500 West Third Avenue, Suite 228, Columbus, OH 43212-2817

Abstract. In 2000 The Ohio Academy of Science published its definition of "Science." Response to this definition led the Academy to produce a position paper entitled *What is Science?* The Academy officially adopted the position paper version of *What is Science?*, http://www.ohiosci.org/Whatisscience.pdf, at the April 2004 Ohio Academy of Science Annual Meeting. Response to this fact sheet demonstrated a need to further expand this document. Thus, this expanded version builds on the April 2004 position paper, *What is Science?* This paper clarifies what is science, the scientific method, a scientific hypothesis, a scientific theory, the importance of science, and what is not science.

OHIO J SCI 106 (4):130-135, 2006

WHAT IS SCIENCE?

The following is a restatement, with minor revision, of The Ohio Academy of Science (2000) definition of science:

> "…science is a systematic method of continuing investigation, based on observation, scientific hypothesis testing, measurement, experimentation, and theory building, which leads to explanations of natural phenomena, processes, or objects, that are open to further testing, revision, and falsification, and while not 'believed in' through faith are accepted or rejected on the basis of scientific evidence."

The US Supreme Court (1993), in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, defined science as:

> "Science is not an encyclopedic body of knowledge about the universe. Instead, it represents a *process* for proposing and refining theoretical explanations about the world that are subject to further testing and refinement (emphasis in original). But, in order to qualify as 'scientific knowledge,' an inference or assertion must be derived by the scientific method. Proposed testimony must be supported by appropriate validation—*i.e.*, 'good grounds,' based on what is known. In short, the requirement that an expert's testimony pertain to 'scientific knowledge' establishes a standard of evidentiary reliability."

The American Heritage® Dictionary (AHD 2000) defines science as: "the observation, identification, description, experimental investigation, and theoretical explanation of phenomena; such activities restricted to a class of natural phenomena; such activities applied to an object of inquiry or study; methodological activity, discipline, or study; an activity that appears to require study and method; knowledge, especially that gained through experience." It defines natural science as: "a science, such as biology, chemistry, or physics, that deals with the objects, phenomena, or laws of nature and the physical worlds." It defines physical science as: "any of the sciences, such as physics, chemistry, astronomy, and geology that analyze the nature and properties of energy and nonliving matter." Restated, science is the study, documentation, and collection of scientific evidence pertaining to observable and quantifiable, naturally occurring objects, phenomena, and processes within the universe, whose results and methodology are publicly released to permit an independent observer to objectively reproduce or falsify the results.

The need for objectivity in documenting the results of a scientific inquiry is that a scientific hypothesis, the scientific experiment designed to answer the question posed by the scientific hypothesis, and the results and conclusions of the experiment must be verifiable or falsifiable by independent observers. Scientific inquiry is restricted to propositions that can be reduced to declarative sentences (a scientific hypothesis) with observable action or actions that are logically connected to observable results by a valid, logical sequence. Science is self-testing, wrote Simpson (Simpson 1964). There is a social, public (published) aspect of science that makes it self-testing, or perhaps, self-correcting (Mellett 2004). When a scientist, regardless of his or her field of expertise, publishes results of his or her work, other scientists should subject that work to verification. Thus, errors in science tend to be detected very quickly. Indeed, one can argue that scientific progress is impossible without the search for error (Mellett 2004). Furthermore, deliberate errors will be purged from science. As David Goodstein (2002) stated, "Science is self-correcting, in the sense that a falsehood injected into the body of scientific knowledge will eventually be discovered and rejected." An example of this is the famous Piltdown Man hoax.

WHAT IS THE SCIENTIFIC METHOD?

Edmund (2005) states that the term "'the scientific method' represents the general pattern of mental activity stages (usually aided by physical activities) that occur in the master method, which we use to obtain, refine, extend, and apply knowledge in all fields. Overall, it represents the system of science and the complete problem solving process. The purpose of the scientific method

[1]Manuscript received 27 July 2006 and in revised form 3 October 2006 (#06-14).

[2]Current Address: Ohio Department of Natural Resources, Division of Geological Survey, 2045 Morse Road, C-2, Columbus, OH 43229-6693
[3]Current Address: The Ohio Academy of Science, 1500 West Third Avenue, Suite 228, Columbus, OH 43212-2817
[4]Current Address: Department of Biological Sciences, Irvine Hall, Ohio University, Athens, OH 45701
[5]Current Address: Janson Industries, Inc., 1200 Garfield Avenue, SW, Canton, OH 44706
[6]Current Address: Precision Machined Products Association, 6700 West Snowville Rd., Brecksville, OH 44141

is to refine, extend, and apply knowledge, and to seek the 'truth,' although the 'truth' can probably never be determined. Results must always be held open for extension, modification, and even possible replacement." The American Heritage® Dictionary (2000) defines the "scientific method" as: "…the principles and empirical processes of discovery and demonstration considered characteristic of or necessary for scientific investigation, generally involving the observation of phenomena, the formulation of a hypothesis concerning the phenomena, experimentation to demonstrate the truth or falseness of the hypothesis, and a conclusion that validates or modifies the hypothesis." Scientific methodology today is based on generating hypotheses and testing them to see if they can be falsified; indeed this methodology is what distinguishes science from other fields of human inquiry (US Supreme Court 1993).

Thus, the scientific method is the "tool" that scientists use to find the answers to questions. The scientific method is not a recipe for making original discoveries or inventions; it does not prescribe the pathway that scientists must follow to attain success. The goal of the scientific method is to ascertain whether a scientific hypothesis is a valid representation of a natural phenomenon, object, or process. Indeed, the nucleus of the scientific method is the confrontation of an idea (scientific hypothesis) with the facts it refers to, regardless of the source of the idea in question. In sum, the scientific method is a means for checking hypotheses for truth rather than for finding facts or inventing ideas (McGraw-Hill 2005).

The following is an amalgam from numerous sources and personal experience as to what constitutes the scientific method:

1. Observe natural objects, phenomena, or processes.
    a. Does observation raise any questions?
    b. Do literature search to see if the question has been previously answered.
    c. If the question has not been answered, identify the problem that needs clarified.
2. Formulate a scientific hypothesis that will answer the question identified in #1.
3. Determine what type of experiment will lead to answer. Experiment planning must identify what variables will be considered, what equipment is required, and how to collect, record and express data.
4. Conduct project experimentation or trials.
    a. Execute experiment.
    b. Record observations and data.
    c. Organize the data.
    d. Analyze the data.
5. Reach a conclusion. Analyze the data or results obtained through the experiment. Do they answer the question posed by the scientific hypothesis?
6. Communicate results.
    a. Prepare a report that presents the data (charts, tables, or graphs).
    b. Document the experiment's methodology.
    c. Discuss the results of the experiment.
    d. Conclude whether or not the scientific hypothesis was proven valid or invalid.
    e. Suggest alternative testing to support or further invalidate the scientific hypothesis.

Science is not a cold, impersonal endeavor devoid of subjectivity. Nobel Laureate Peter Medawar (1979) expressed this concept stating: "The scientific ideal of an absolute truth divorced from human judgment is a dangerous fallacy that seriously impedes progress." Clearly subjectivity and personal bias are demonstrated every time a scientist chooses what to observe (see #1 above), formulation of the question (see #2 above), how to design the experiment (see #3 above), how to collect and analyze the data (see #4 above), and how to communicate the experiment's result (see #5 above). However, by following the scientific method the documented experimental design (see #3 above) and its ability to generate data can be objectively followed and reproduced by any independent observer, hence the source of the objectivity of science. An analogy to the scientific method and its subjectivity and ultimate objectivity, derived from the culinary world, would be a baker conceiving the idea for a new pie. The baker must first determine what type of pie (fruit, cream, or custard) he or she wants to create (see #1 & #2 above), what ingredients are needed (see #3 above), how to assemble it (see #3 above), produce the pie (see #3 above), taste the pie (see #4 above), decide if the pie is tasty or not (see #4 above), and if tasty, write up the recipe documenting the ingredients and directions (see #4 & #5 above). The baker then must share (e-mail, post on internet, or publish) the recipe so other bakers can make and verify that the pie is, indeed, tasty (see #6 above).

WHAT IS A "SCIENTIFIC HYPOTHESIS"?

The American Heritage® Dictionary (2000) defines hypothesis, with regard to science, as: "a tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation." A scientific hypothesis often is a declarative statement that is a proposed solution to a particular problem or question about observable natural phenomena, objects, or processes. Scientific hypotheses can also deal with unobservable natural phenomena, objects, or processes as David Goodstein (2003) (personal communication 2006) states: "Modern science is full of things that cannot be observed at all, such as force fields and complex molecules. However, they can be quantified even if only indirectly." Warren Allmon (2005) states,

> "Unique, non-repeatable historical events cannot be studied scientifically and depend on faith just as much as religion does. Even unique, non-repeatable events, which cannot be experimentally manipulated or observed directly, leave material results that can be studied scientifically. Crimes are not literally repeated and yet investigators use material evidence to solve them. Human history cannot be repeated, and yet we use written and other records to decipher what events occurred when. We observe the present and extrapolate what we see to the past."

Whether scientific hypotheses deal with an observable or unobservable aspect of nature, their statement and methodology must be testable to yield valid, quantifiable, and objectively reproducible results or findings in the form of observations and deductions that either verify or reject the scientific hypothesis. Michael Gough (2003) states, "… hypotheses can be imagined that require the intervention of God or magic or a specialized skill, but those are not scientific. To be scientific, a hypothesis must describe events in the physical world, and it can be tested in many detailed and specific ways."

As Nobel Laureate François Jacob (1988) stated,

> "contrary to what I once thought, scientific progress does not consist simply in observing, in accumulating experimental facts, and drawing up a theory from them. It began with the invention of a possible world, or a fragment thereof, which was then compared by experimentation with the real world."

Perhaps stated in slightly less eloquent terms, scientific hypotheses are formulated from observations of natural objects, phenomena, or processes that lead the observer to question the observation and to attempt to formulate a means to explain logically the observed objects, phenomena, or processes, and provide a template by which an independent observer can reproduce the explanation.

A scientific hypothesis is testable and expandable in order to accommodate new data derived through application of the scientific method. This accommodation may reveal additional insight into the nature of the objects, phenomena, or processes. Evaluating a scientific hypothesis in light of the results of an experiment yields four possible outcomes:

1. The experiment can show a scientific hypothesis to be consistent with facts already established. In this manner, the scientific hypothesis is proven valid because it demonstrates consistency with things as they are presently and experimentally documented. **(Consistent with known facts)**
2. The objective data produced by alternative experiments supports the prediction or expectations offered by the scientific hypothesis. Repeated experimental confirmation demonstrates the original scientific hypothesis' strength as a satisfactory explanation for an experiment's demonstrated results. **(Supported by new facts)**
3. Repeated experiments that produce results consistent with those expected for a scientific hypothesis demonstrate it is a sufficient description of natural objects, phenomena, or processes. **(Sufficiency of hypothesis)**
4. Experimental results inconsistent with the expectations of a scientific hypothesis identify areas for further research and perhaps may indicate insufficiency or inadequacy of the scientific hypothesis as an accurate and complete reflection of the nature of the phenomena or processes under investigation. **(Rejection of hypothesis)**

The scientific community addresses any discrepancies between a scientific hypothesis's expected results and the actual results; this, in turn, drives further experimentation, further scientific hypothesizing, and leads to new areas of research. Inconsistencies are as important as consistencies as they drive efforts to self-correct or continuously improve the scientific hypotheses.

WHAT DOES "THEORY" MEAN IN SCIENCE?

The term "*theory,*" as used in science, does not mean abstract reasoning; speculation (for example, a decision based on experience rather than theory); a belief or principle that guides action or assists comprehension or judgment (for example, staked out the house on the theory that criminals usually return to the scene of the crime); or an assumption based on limited information or knowledge—a conjecture (AHD 2000). The American Heritage® Dictionary (2000) defines "*theory,*" with regard to science, as: "a set of statements or principles devised to explain a group of facts or phenomena, especially one that has been repeatedly tested or is widely accepted and can be used to make predictions about natural phenomena." In science, a "*theory*" represents the highest level of confidence in a scientific explanation describing or predicting the action of a natural object, phenomenon, or process. The high level of confidence that the "*theory*" is valid is based on repeated application of the scientific method—observation, hypothesis formulation, experimentation, repeated hypothesis testing, and objective verification of the scientific theory's ability to predict or explain the natural universe. Thus, a scientific theory encompasses a well-documented assembly of related rules, repeatable results, concepts, and conceptual models that confidently and objectively describe, predict, and explain natural objects, phenomena, and processes.

Scientific theories produced and strengthened by repeated application of the scientific method help to organize or explain our knowledge of a particular natural object, phenomenon, or process. A theory, as such, is never proven right or wrong; it is either useful as an explanation or not. If not, it is rejected. Theories that are not rejected have different degrees of robustness depending on the strength of the evidence supporting them. Put another way, if a theory makes novel and unexpected predictions, and those predictions are verified by scientific experiments that reveal new, useful, or interesting data, observations, or interactions regarding a natural object, phenomenon, or process then the chances that the theory is correct are greatly enhanced. Even if it is not correct, it has been fruitful in the sense that it has led to the discovery of previously unknown phenomena that might prove useful in themselves and that will have to be explained by the next theory that comes along (Goodstein 2003).

Established scientific theories may stand unchanged from their conception until or after new data are discovered, tested, and verified, or a new theory, which more precisely explains an object, phenomenon, or process is developed, tested, and accepted. A new scientific theory that better explains a natural object, phenomenon, or process often replaces an existing theory. Unfortunately, when such a replacement occurs, it is assumed by the scientifically illiterate that the replaced theory was wrong and, thus, it was overthrown. Regardless if the new theory was the result of just a minor revision of an existing theory, many people view this as justification for claiming all information obtained during testing of the replaced theory is invalid. The attempt to dismiss known facts because they subsequently support an even stronger scientific theory represents the pinnacle of intellectual dishonesty or at least a clear demonstration of a lack of scientific literacy. The American Association for the Advancement of Science (1989) defines a "scientific literate person" as: "one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes."

During the course of human history many scientific theories have been developed. Some of these theories have stood unaltered for centuries while others have been revised, sometimes repeatedly, as new data, improved testing apparatus, and repeated experiments and observations have taken place. For example, David Goodstein (2003) wrote, with minor author alteration,

> "the new sciences of quantum mechanics and relativity, for example, did indeed show that Newton's laws of mechanics were not the most fundamental laws of nature. However, they did not show that they were wrong. Quite the contrary, they showed why Newton's laws of mechanics were right, it is just that quantum mechanics and relativity covered a wider range of circumstances unimagined by Newton and his followers, such as things as small as atoms, or nearly as fast as the speed of light, or as dense black holes. Despite what quantum mechanics and relativity explain about the natural universe, Newton's laws go on working just as well as they always did. Thus, there is no ambiguity at all about which paradigm is better. The new laws of quantum mechanics and relativity subsume and enhance the older Newtonian world."

Another example of how an existing paradigm can be altered without abandoning the older concept is John Dalton's development of the modern atomic theory in 1803 (Carpi 2003a). His theory had four main concepts:

1. All matter is composed of indivisible particles called atoms.
2. All atoms of a given element are identical; atoms of different elements have different properties.
3. Chemical reactions involve the combination of atoms, not the destruction of atoms.
4. When elements react to form compounds, they react in defined, whole number ratios.

Because of John J. Thomson's 1897 discovery of electrons, atoms were no longer thought to be solid, indivisible spheres, but Dalton's concept of matter composed of atoms did not change. Ernst Rutherford's 1911 theory extended Thomson's work of an atom resembling a miniature solar system with electrons freely orbiting a central nucleus (Carpi 2003b). Rutherford's theory was quickly replaced by Neils Bohr's 1913 atom concept. Bohr's theory instead, explained that electrons act more like probability cloud surrounding the atomic nucleus, in quantum energy shells with the electron or electrons in any given shell conceivably being present at any point at any given moment within its energy shell (Carpi 2003c). Even though the concept of how an atom may appear changed, the fundamentals underlying the concept of Atomic Theory have not changed; atoms are still composed of protons, neutrons, and electrons and are the fundamental particles that make up all matter.

Besides the "Atomic Theory," many theories have been modified through time, becoming even stronger in their explanation of naturally occurring objects, phenomena, or processes.

> "The usefulness of scientific theories, like those on gravity, relativity, and evolution, is to make predictions. When theories make practicable foresight possible, they are widely accepted and used to make all the new things that we enjoy—like global positioning systems, which rely on the theories of relativity, and the satellites that make them possible, which are placed in their orbits thanks to the theory of gravity" (Thorp 2006).

The histories of two of the thousands of scientific theories are included in the Appendix.

WHAT IS NOT SCIENCE?

In contrast to what is science, a scientific hypothesis, and a scientific theory, any statement about nature not objectively quantifiable by an independent observer, relying—regardless of the degree—on subjectivity, personal opinion, belief, or supernatural element to validate a conclusion about a natural object, phenomenon, or process is, by definition, not science. Stated another way, science does not deal with the supernatural or with questions or issues for which no material or physical evidence exists; it is about seeking material causes for material phenomena (Allmon 2005). If someone interjects a non-objective or non-quantifiable variable into an equation in order to reach a conclusion, the statement is by definition outside the realm of science. Often these variables involve qualitative comparisons such as right versus wrong, beautiful versus ugly, wise versus unwise, or desirable versus undesirable. Although society has determined acceptable subjective standards for defining these and other such comparisons, they are not objective, quantifiable concepts and thus will always fail the test of being science. Furthermore, these types of statements also deal with ethics and values, expressing the beliefs, mores, and morals that condition and guide societal behavior. Combined with an accepted belief structure, these concepts also serve as the foundation of religions. Examples of these "societal" statements are "love thy neighbor" or "be kind to animals." However, whether comparative, social, or religious, these statements have an element of subjectivity (for example, beauty is in the eye of the beholder) and, therefore, they cannot be considered a scientific statement. Thus, any hypothesis, theory, or concept that requires the incorporation of a subjective belief, opinion, element, or supernatural creator/designer, to reach its conclusion is not fact-based objective science. Why are supernatural elements not permitted in science? We know of no valid experiment designed to prove the existence of anything supernatural.

WHAT IS THE IMPORTANCE OF SCIENCE?

Science is more than just a collection of data. Science is a tool used to objectively explain the ever-changing, natural universe in which we live. Science provides an objective, systematic, self-correcting way to determine when to accept or reject a theory or concept regarding the natural universe. The repeated application of the scientific method has enabled humanity to develop and improve our understanding of the natural universe by using the pragmatism of demonstration, the objectivity of mathematical and statistical analysis, and the observational power of all people.

Science has changed the way we view the natural universe. When joined with engineering, modern technology, and the global economic system, the methods and results of scientific inquiry have profoundly affected humanity's material and societal progress. Vannevar Bush (1945), who participated in the establishment of the National Science Foundation, aptly described the value of scientific endeavor when he stated in 1945:

> "Advances in science when put to practical use mean more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without the deadening drudgery which has been the burden of the common man for ages past. Advances in science will also bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression. But to achieve these objectives—to secure a high level of employment, to maintain a position of world leadership—the flow of new scientific knowledge must be both continuous and substantial.
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> Our population increased from 75 million to 130 million between 1900 and 1940. In some countries comparable increases have been accompanied by famine. In this country the increase has been accompanied by more abundant food supply, better living, more leisure, longer life, and better health. This is, largely, the product of three factors—the free play of initiative of a vigorous people under democracy, the heritage of great national wealth, and the advance of science and its application.
>
> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world."

Science is a one-way knowledge ratchet that advances one or more clicks when new facts, hypotheses, principles, theories, and laws are objectively fused to the amalgam of human expertise, thereby preserving that new scientific knowledge for our collective human accomplishment and betterment.

CONCLUSION

In conclusion, science is a systematic, fact-based discipline, which is often incremental in its approach in validating scientific hypotheses and theories about natural objects, phenomena, and processes. Science is advanced by experimental design and results derived through the repeated application of the scientific method. Utilizing the scientific method, a scientist leaves his or her experiment, results, and conclusions open to objective analyses by independent observers. Scientific theories are strengthened through time by the application or reapplication of the scientific method that either confirms or falsifies the theory as an explanation of the natural universe. In contrast, any attempt to explain naturally occurring observable or unobservable objects, processes, or phenomena by the incorporation of subjective opinion, personal belief, or supernatural elements to validate a conclusion cannot be objectively analyzed and, therefore, is not science.

Acknowledgment. The foregoing is an amalgam of statements from William Hummon, Richard Janson, Miles Free, Douglas Shrake, Lynn Elfner and the collective knowledge of scientists who have preceded us. We wish to thank our numerous colleagues and two anonymous reviewers who have provided insight on how to improve this paper.

LITERATURE CITED

Allmon WD. 2005. Evolution and Creationism: A Guide for Museum Docents, Version 3.0. Ithaca (NY): Museum of the Earth. www.priweb.org

[AHD] American Heritage® Dictionary of the English Language, Fourth Edition. 2000. Houghton Mifflin Co.

American Association for the Advancement of Science. 1989. Science for all Americans. New York: Oxford Univ Pr.

Brennan RP. 1992. Dictionary of Scientific Literacy. New York: John Wiley. 334 p.

Bush V. 1945. Science the Endless Frontier: A report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, July 1945. Washington (DC): US Government Printing Office. 34 p.

Carpi A. 2003a. Matter: Atoms from Democritus to Dalton, Visionlearning Vol. CHE-1 (1). http://www.visionlearning.com/library/module_viewer.php?mid=49

Carpi A. 2003b. Atomic Theory I: The Early Days, Visionlearning Vol. CHE-1 (2). http://www.visionlearning.com/library/module_viewer.php?mid=50

Carpi A. 2003c. Atomic Theory II: Ions, Isotopes and Electron Shells, Visionlearning Vol. CHE-1 (3). http://www.visionlearning.com/library/module_viewer.php?mid=51

Edmund NW. 2005. Report on the relationship of the scientific method to scientifically valid research and education research. http://www.scientificmethod.com

Frazier K, editor. 1985. Solar System (Planet Earth Series). Alexandria (VA): Time-Life Books. 176 p.

Goodstein D. 2002. Scientific Misconduct, Academe Online, v. 88, n.1

Goodstein D. 2003. How Science Works. In: Reference Manual on Scientific Evidence, 2nd ed. p 1-16.

Gough M, editor. 2003. Politicizing Science: The Alchemy of Policymaking. Stanford (CA): Hoover Institution Pr. 327 p.

Intute: Science, Engineering, and Technology. 2006. Solar System Timeline. http://www.intute.ac.uk/sciences/timeline_Solar_System.html

Jacob F. 1988. The Statue Within: An Autobiography. Cold Spring Harbor (NY): Cold Spring Harbor Laboratory Pr. 338 p.

Lochner J. 1998. NASA's Imagine the Universe!, Imagine Home, Ask an Astrophysicist-Heliocentric Solar System. http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/980212a.html

McGraw-Hill Encyclopedia of Science and Technology. 2005. "Scientific Method." McGraw-Hill Companies, Inc. Answers.com 22 Sep 2006.

Medawar PB. 1979. Advice to a Young Scientist. Canada: Harper-Collins Publ. 128 p.

Mellett JS. 2004. Question: Do you believe in Evolution? – Answer: Do you believe in Gravity? Viewpoint, The Professional Geologist. American Institute of Professional Geologists. p 33-6.

The Ohio Academy of Science. 2000. What is Science? Columbus (OH): The Ohio Academy of Science. Policy Resolution.

The Ohio Academy of Science. 2004. What is Science? Columbus (OH): The Ohio Academy of Science. 2 p.

Simpson GG. 1964. This View of Life. New York: Harcourt, Brace. 308 p.

Smith HE. 1999. Gene Smith's Astronomy Tutorial: A Brief History of Astronomy. 16 April 1999 version: http://casswww.ucsd.edu/

public/tutorial/History.html
Thorp H. 2006. Evolution's Bottom Line (Opinion). New York Times, 12 May 2006.
[USGS] United States Geological Survey. 2006. This dynamic earth: the story of plate tectonics—online edition. In: Kious WJ, Tilling RI. This Dynamic Earth: The Story of Plate Tectonics, 1996. http://pubs.usgs.gov/gip/dynamic/
United States Supreme Court. 1993. Daubert v. Merrell Dow Pharmaceuticals, Inc. Accessed 3 Oct 2006 at: http://straylight.law.cornell.edu/supct/html/92-102.ZO.html

Appendix

Geocentric versus Heliocentric Model of the Solar System

The following discussion of the theory of the Solar System is adapted from Frazier (1985), Lochner (1998), Smith (1999), and Intute: Science, Engineering, and Technology (2006). The first recorded conclusions about the solar system were set down by the Sumerians of the Middle East (ca. 3036 BC). To them the Earth was flat, motionless, and was clearly the center of the universe. Other early civilizations—such as the Chinese, Babylonian, and Egyptian—had much the same geocentric concept. The Greeks began to attempt to explain the heavens around 600 BC. In 270 BC, Aristarchus of Samos (310-230 BC) presented the theory that the Sun was the center of the solar system (Heliocentric) and that the Earth and other planets revolved around it. This concept sounds remarkably similar to the model of the Solar System used today. However, the road back to Aristarchus's theory was a long one. In 140 AD, Claudius Ptolemaeus, better known as Ptolemy, put forth another version of planetary motion. Ptolemy's model/theory for the Solar System was that the Earth was the unmoving center of the Solar System/Universe (Geocentric). His theory of the Solar System survived for centuries, even being incorporated into the Catholic Church's dogma on the nature of the universe. That dogma is that by God's design, Earth lay at the center of things, unmoving, and the heavens as defined by Ptolemy were perfection, complete. No one dared question Ptolemy's theory until Mikolaj Kopernik, better known by his Latin name, Copernicus, did so. Copernicus labored in secret for 20 years to develop his heliocentric theory, finally completing his work in 1533. During the next 10 years, he only told a few associates of his idea. In 1543, he published his works, *De Revolutionibus Orbium Coelestium*, virtually on his deathbed. Copernicus cited, some 1,800 years later, the work of Aristarchus in his notes. The debate between the Ptolemaic versus Copernican theory of the Solar System was still going on in 1600 AD when Dominican monk and philosopher Giordano Bruno was executed by the Inquisition for failing to recant his belief in a Copernican heliocentric Solar System. Johannes Kepler began working with Tycho Brahe in Prague in the same year. Kepler, expanding on Brahe's work, realized that he, like many before him, had been in error thinking that the planets moved in perfect circles. Brahe's work had still been based on planetary movement being concentric about the Sun and the Earth being stationary. Kepler's first two laws of planetary movement, published in 1609, and his third law in 1619 correctly explained most of the discrepancies of earlier planetary theory. Galileo Galilei, a contemporary of Kepler, became obsessed with the Dutch spyglass invention (telescope). He began constructing various telescopes in 1609 and used them to study the night sky. Galileo's numerous observations supported Aristarchus and Copernicus's heliocentric solar system model, not the Catholic Church's accepted dogma of Ptolemy's geocentric model. In 1632, Galileo published his book, *Dialogue on the Two Chief World Systems* (historic note, the Pilgrims landed at Plymouth Rock in 1620) in which he supports Copernicus's heliocentric solar system model. In 1633, he was ordered to Rome to state his case before the Inquisition. Galileo was forced to disavow his work, and was sentenced to house arrest for the remainder of his life. The Catholic Church finally recanted its geocentric position in 1742. Thus, it took 2,012 years for Aristarchus's theory of how the Solar System works to become today's accepted model.

Unfortunately, there is still much progress to be made on advancing this concept as a joint poll conducted by the Northern Illinois University and Oxford University in 1989 demonstrated. The poll showed only one-third of the British adults and one-half of the Americans knew that the Earth revolves around the Sun and takes one year to do so (Brennan 1992).

The Theory of Continental Drift/Plate Tectonics

The concept of plate tectonics is another theory that has undergone many changes since first formally put forth as the theory of continental drift by meteorologist Alfred L. Wegener in 1912 (USGS 2006). Abraham Ortelius, a Dutch mapmaker, first hypothesized this concept in 1596, but for over three centuries, this theory was not widely accepted and little rigorous testing was done. Even after Wegener proposed his theory of continental drift, based and supported by fossil correlation between continents and physical evidence of mismatched fossils and climate, critics questioned how such large land masses could move—his explanation of the theory did not adequately address the critics' concern. He spent the rest of his life looking for evidence that could support his theory. Thirty years after his death, detailed mapping of the ocean floor and the development of paleomagnetic geophysical exploration spawned renewed interest in the theory of continental drift. The theory of seafloor spreading was developed based on the physical observations of the mid-oceanic ridges and provided support to the theory of continental drift. However, since the two theories were so closely related, a new theory, the theory of plate tectonics, was proposed to incorporate both of the concepts.

The theory of plate tectonics has been rigorously tested during the past four decades and it has held up as a sound and unifying scientific theory. It is now widely accepted and explains the locations of volcanoes, earthquakes, mountain ranges, and the shape and positions of the continents (see http://pubs.usgs.gov/gip/dynamic).