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Science & Spaghetti Monsters: Understanding the Nature of Scientific Knowledge & Research

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What is science?

When students are asked to define science, many of them define science as "a body of knowledge gained by performing experiments."

A more appropriate definition, however, is that "Science is … a process of inquiry aimed at building a testable body of knowledge open to rejection or confirmation" (Shermer, 2005).

There are three important points that this definition makes:

First, it defines science as a "process." The process is one in which information is gathered about the natural world through both observation and experimentation. Hypothesis testing, data analysis, logical reasoning, and inferential thinking are all very important aspects of developing this information. The results produced are supported by evidence and are used to understand, describe and explain the natural world.

[Note: This is why in this class we focus on processes (making observations, analyzing data, providing explanations, generating new scenarios, etc.), as well as facts and knowledge.]

Students often think that science is done through a set of sequential steps called the "scientific method." Sometimes that is the case, but in the "real world," scientists frequently perform the procedures defined by this method (hypothesis creation, etc.) in a completely different order, or they disregard some or most of them entirely.

Does that mean they aren't doing science correctly? NO! It just means that the process isn't always linear. Sometimes you collect data, come up with more hypotheses, do more experiments, run into problems, figure out better ways to test, and more before you can ever draw a conclusion.

Second, science deals with ideas or hypotheses that are **falsifiable** and **testable**. If you can't think of any evidence that would disprove some idea or hypothesis, or if there is no way of testing it (e.g., by evaluating the accuracy of predictions based on it), then it is *not* accepted in science. [Note: Ideas or hypotheses that are conceptually falsifiable but untestable due to technological limitations are still scientific, but they will not reach a point of acceptance without supporting evidence.]

Another way of saying this is that science is a study of the "natural world." The supernatural (i.e., that which is attributed to magical or miraculous forces that violate or extend beyond natural processes) is outside of the realm of science. Explanations or claims that rely in whole or in part on supernatural causation are not accepted as science and don't belong in the science classroom.

For example, I could say that an invisible, undetectable, all powerful spaghetti monster with meatball eyes controls the universe. As a scientist, the correct response to me is not "wow, that's silly and I disagree," but "since we lack the ability to test or falsify your belief based on its very definition, as scientists, we don't consider your explanation scientific and cannot discuss or asses its validity."

Third, the body of knowledge produced by science is "**open to rejection or confirmation.**" Nothing is accepted with *absolute* certainty. Everything is subject to review, revision, refinement or rejection based on further evidence. A word like "proven" is considered absolute, so we tend to say "supported with evidence" instead.

Does this mean you can't "trust" anything in science? NO! It just means that the field of science is flexible, and can adapt to new information and evidence so that our understanding of the natural world is constantly enhanced.

<u>This is one of the greatest strengths of science</u>. If scientists ignored new data, evidence, and explanations because they claimed to know the <u>absolute truth</u>, then we might still have misconceptions like the Earth is flat, or is at the center of the universe!

What then is a "scientific fact" if no information is accepted with 100% certainty? Well, the word fact is used by scientists in two ways. First, it is used to denote observations that are objective and verifiable. Second, it is used to describe those things that are so strongly supported by evidence that the likelihood of them being wrong is infinitesimally small. In other words, scientific facts are those things that, based on empirical evidence, are accepted with 99.99+% confidence. For example, it is considered a scientific fact that polio is caused by a virus.

What are hypotheses, theories and laws in science?

The word "theory" in casual conversations is often used to mean an educated guess. However, that description is more applicable to a hypothesis. A hypothesis, even more thoroughly defined, is a statement, idea, or explanation that currently lacks convincing evidentiary support.

Hypotheses are speculative and scientists test them by trying to disprove them. A test that fails to disprove a hypothesis (e.g., one that finds evidence that only confirms the hypothesis) can lend support to the hypothesis, but it does *not* prove it true.

In science, the word **theory** has a completely different meaning than "educated guess." Theories in science are the powerful ideas or sets of ideas that **explain** the natural world. It is a comprehensive explanation for a complex set of phenomena or large number of observations and facts. ***The word theory, as used in science, does not at all imply a lack of confidence***.

The most powerful theories in science make bold predictions that have withstood many years of scrutiny and testing, and they explain numerous phenomena and observations that were previously unexplained. Evolutionary theory, for example, explains the origin and diversity of species, and it explains the adaptations that we see in organisms. Some other examples of powerful scientific theories would be the atomic theory, the theory of plate tectonics, the germ theory of disease, and the chromosome/gene theory of inheritance.

Laws in science, by contrast, are generalizations, statements, or mathematical expressions that **describe** the natural world. More specifically, laws usually describe patterns, trends, or relationships between variables under a given set of conditions. Boyle's law, for example, describes the relationship between the pressure and volume of a gas when the temperature and number of moles are held constant. Laws often come in the form of equations.

Because people have misconceptions about what a theory is in science, they draw the conclusion that only laws are held with a high degree of confidence. However, both theories and laws are testable, falsifiable constructs that are supported by an abundance of observational and/or experimental evidence. One is no more tentative than the other, nor does one ever become the other.

Contrary to popular belief, no scientific theory ever became a law and there is no hierarchical step to advance to beyond the level of scientific theory. Hypotheses, however, can become either laws or theories based on what they do. **Descriptive** hypotheses have the potential to become scientific laws; and **explanatory** hypotheses, if they are wide enough in scope, have the potential to become scientific theories. This transformation into either a law or a theory requires a compelling amount of strong evidentiary support.

Because there is no hierarchy, and theories show vast and compelling amounts of evidence through their explanatory power, the popular criticism that something is in science is "only a theory" is inaccurate and unsupportable.

The overarching theory of the field of biology is evolution. Evolution is **the ONLY scientific explanation** for the origin and diversity of species and the adaptations that we see in organisms. Therefore, it is the *only* explanation that should be taught in a biology classroom. It is also supported by numerous lines of evidence from various fields of science, so much so that it is considered a scientific "fact." You will be introduced to some of these lines of evidence in your SI Biology class.

More information about the content covered in this document can be found at:

Evolution Resources from the National Acadmies. (2010). Retrieved from nationalacademies.org: http://www.nationalacademies.org/evolution/TheoryOrFact.html

Misconceptions FAQ. (2011). Retrieved from Understanding Evolution : http://evolution.berkeley.edu/evolibrary/misconceptions_faq.php#a1

National Science Education Standards. 1996. National Academy Press. 262 p.

Shermer, Michael. 2005. Science Friction: Where the Known Meets the Unknown. Times Books. 336 p.

Science for All Americans. 1990. American Association for the Advancement of Science Press. 272 p.

Science, Evolution, and Creationism. (2008). Retrieved from National Academies Press: http:www.nap.edu/catalog.php?record_id=11876