Session 1.

Sciences of education

The Definition of Science

Science is not merely a collection of facts, concepts, and useful ideas about nature, or even the systematic investigation of nature, although both are common definitions of science. Science is a method of investigating nature--a way of knowing about nature--that discovers reliable knowledge about it. In other words, science is a method of discovering reliable knowledge about nature. There are other methods of discovering and learning knowledge about nature (these other knowledge methods or systems will be discussed below in contradistinction to science), but science is the only method that results in the acquisition of reliable knowledge.

Reliable knowledge is knowledge that has a high probability of being true because its veracity has been justified by a reliable method. Reliable knowledge is sometimes called justified true belief, to distinguish reliable knowledge from belief that is false and unjustified or even true but unjustified. (Please note that I do not, as some do, make a distinction between belief and knowledge; I think that what one believes is one's knowledge. The important distinction that should be made is whether one's knowledge or beliefs are true and, if true, are justifiably true. Every person has knowledge or beliefs, but not all of each person's knowledge is reliably true and justified. In fact, most individuals believe in things that are untrue or unjustified or both: most people possess a lot of unreliable knowledge and, what's worse, they act on that knowledge! Other ways of knowing, and there are many in addition to science, are not reliable because their discovered knowledge is not justified. Science is a method that allows a person to possess, with the highest degree of certainty possible, reliable knowledge (justified true belief) about nature. The method used to justify scientific knowledge, and thus make it reliable, is called the scientific method. I will explain the formal procedures of the scientific method later in this essay, but first let's describe the more general practice of scientific or critical thinking. (Steven D. Schafersman in the Department of Geology at Miami University.)

Biology literally means "the study of life". Biology is such a broad field, covering the minute workings of chemical machines inside our cells, to broad scale concepts of ecosystems and global climate change. Biologists study intimate details of the human brain, the composition of our genes, and even the functioning of our reproductive system. Biologists recently all but completed the deciphering of the human genome, the sequence of deoxyribonucleic acid (DNA) bases that may determine much of our innate capabilities and predispositions to certain forms of behavior and illnesses. DNA sequences have played major roles in criminal cases (O.J. Simpson, as well as the reversal of death penalties for many wrongfully convicted individuals), as well as the impeachment of President Clinton (the stain at least did not lie). We are bombarded with headlines about possible health risks from favorite foods (Chinese, Mexican, hamburgers, etc.) as well as the potential benefits of eating other foods such as cooked tomatoes. Informercials tout the benefits of metabolism-adjusting drugs for weight loss. Many Americans are turning to herbal remedies to ease arthritis pain, improve memory, as well as improve our moods.

Can a biology book give you the answers to these questions? No, but it will enable you learn how to sift through the biases of investigators, the press, and others in a quest to critically evaluate the question. To be honest, five years after you are through with this class it is doubtful you would remember all the details of meatbolism. However, you will know where to look and maybe a little about the process of science that will allow you to make an informed decision. Will you be a scientist? Yes, in a way. You may not be formally trained as a science major, but you can think critically, solve problems, and have some idea about what science can and cannoit do. I hope you will be able to tell the shoe from the shinola.

Science and the Scientific Method | Back to Top

Science is an objective, logical, and repeatable attempt to understand the principles and forces operating in the natural universe. Science is from the Latin word, scientia, to know. Good science is not dogmatic, but should be viewed as an ongoing process of testing and evaluation. One of the hoped-for benefits of students taking a biology course is that they will become more familiar with the process of science.

Humans seem innately interested in the world we live in. Young children drive their parents batty with constant "why" questions. Science is a means to get some of those whys answered. When we shop for groceries, we are conducting a kind of scientific experiment. If you like Brand X of soup, and Brand Y is on sale, perhaps you try Brand Y. If you like it you may buy it again, even when it is not on sale. If you did not like Brand Y, then no sale will get you to try it again.

In order to conduct science, one must know the rules of the game (imagine playing Monopoly and having to discover the rules as you play! Which is precisely what one does with some computer or videogames (before buying the cheatbook). The scientific method is to be used as a guide that can be modified. In some sciences, such as taxonomy and certain types of geology, laboratory experiments are not necessarily performed. Instead, after formulating a hypothesis, additional observations and/or collections are made from different localities.

Steps in the scientific method commonly include:

Observation: defining the problem you wish to explain.

Hypothesis: one or more falsifiable explanations for the observation.

Experimentation: Controlled attempts to test one or more hypotheses.

Conclusion: was the hypothesis supported or not? After this step the hypothesis is either modified or rejected, which causes a repeat of the steps above.

After a hypothesis has been repeatedly tested, a hierarchy of scientific thought develops. Hypothesis is the most common, with the lowest level of certainty. A theory is a hypothesis that has been repeatedly tested with little modification, e.g. The Theory of Evolution. A Law is one of the fundamental underlying principles of how the Universe is organized, e.g. The Laws of Thermodynamics, Newton's Law of Gravity. Science uses the word theory differently than it is used in the general population. Theory to most people, in general nonscientific use, is an untested idea. Scientists call this a hypothesis.

Scientific experiments are also concerned with isolating the variables. A good science experiment does not simultaneously test several variables, but rather a single variable that can be measured against a control. Scientific controlled experiments are situations where all factors are the same between two test subjects, except for the single experimental variable.

Consider a commonly conducted science fair experiment. Sandy wants to test the effect of gangsta rap music on pea plant growth. She plays loud rap music 24 hours a day to a series of pea plants grown under light, and watered every day. At the end of her experiment she concludes gangsta rap is conducive to plant growth. Her teacher grades her project very low, citing the lack of a control group for the experiment. Sandy returns to her experiment, but this time she has a separate group of plants under the same conditions as the rapping plants, but with soothing Led Zeppelin songs playing. She comes to the same conclusion as before, but now has a basis for comparison. Her teacher gives her project a better grade.

Theories Contributing to Modern Biology | Back to Top

Modern biology is based on several great ideas, or theories:

The Cell Theory

The Theory of Evolution by Natural Selection

Gene Theory

Homeostasis

Robert Hooke (1635-1703), one of the first scientists to use a microscope to examine pond water, cork and other things, referred to the cavities he saw in cork as "cells", Latin for chambers. Mattias Schleiden (in 1838) concluded all plant tissues consisted of cells. In 1839, Theodore Schwann came to a similar conclusion for animal tissues. Rudolf Virchow, in 1858, combined the two ideas and added that all cells come from pre-existing cells, formulating the Cell Theory. Thus there is a chain-of-existence extending from your cells back to the earliest cells, over 3.5 billion years ago. The cell theory states that all organisms are composed of one or more cells, and that those cells have arisen from pre-existing cells.

Figure 1. James Watson (L) and Francis Crick (R), and the model they built of the structure of deoxyribonucleic acid, DNA. While a model may seem a small thing, their development of the DNA model fostered increased understanding of how genes work. Image from the Internet.

In 1953, American scientist James Watson and British scientist Francis Crick developed the model for deoxyribonucleic acid (DNA), a chemical that had (then) recently been deduced to be the physical carrier of inheritance. Crick hypothesized the mechanism for DNA replication and further linked DNA to proteins, an idea since referred to as the central dogma. Information from DNA "language" is converted into RNA (ribonucleic acid) "language" and then to the "language" of proteins. The central dogma explains the influence of heredity (DNA) on the organism (proteins).

Homeostasis is the maintainence of a dynamic range of conditions within which the organism can function. Temperature, pH, and energy are major components of this concept. Theromodynamics is a field of study that covers the laws governing energy transfers, and thus the basis for life on earth. Two major laws are known: the conservation of matter and energy, and entropy. These will be discussed in more detail in a later chapter. The universe is composed of two things: matter (atoms, etc.) and energy.

These first three theories are very accepted by scientists and the general public. The theory of evolution is well accepted by scientists and most of the general public. However, it remains a lightening rod for school boards, politicians, and television preachers. Much of this confusion results from what the theory says and what it does not say.

Development of the Theory of Evolution | Back to Top

Modern biology is based on several unifying themes, such as the cell theory, genetics and inheritance, Francis Crick's central dogma of information flow, and Darwin and Wallace's theory of evolution by natural selection. In this first unit we will examine these themes and the nature of science.

The Ancient Greek philosopher Anaxiamander (611-547 B.C.) and the Roman philosopher Lucretius (99-55 B.C.) coined the concept that all living things were related and that they had changed over time. The classical science of their time was observational rather than experimental. Another ancient Greek philosopher, Aristotle developed his Scala Naturae, or Ladder of Life, to explain his concept of the advancement of living things from inanimate matter to plants, then animals and finally man. This concept of man as the "crown of creation" still plagues modern evolutionary biologists (See Gould, 1989, for a more detailed discussion).

Post-Aristotlean "scientists" were constrained by the prevailing thought patterns of the Middle Ages -- the inerrancy of the biblical book of Genesis and the special creation of the world in a literal six days of the 24-hour variety. Archbishop James Ussher of Ireland, in the late 1600's calculated the age of the earth based on the geneologies from Adam and Eve listed in the biblical book of Genesis. According to Ussher's calculations, the earth was formed on October 22, 4004 B.C. These calculations were part of Ussher's book, History of the World. The chronology he developed was taken as factual, and was even printed in the front pages of bibles. Ussher's ideas were readily accepted, in part because they posed no threat to the social order of the times; comfortable ideas that would not upset the linked applecarts of church and state.

Figure 2. Archbishop James Ussher. Image from the Internet.

Often new ideas must "come out of left field", appearing as wild notions, but in many cases prompting investigation which may later reveal the "truth". Ussher's ideas were comfortable, the Bible was viewed as correct, therefore the earth must be only 5000 years old.

Geologists had for some time doubted the "truth" of a 5,000 year old earth. Leonardo da Vinci (painter of the Last Supper, and the Mona Lisa, architect and engineer) calculated the sedimentation rates in the Po River of Italy. Da Vinci concluded it took 200,000 years to form some nearby rock deposits. Galileo, convicted heretic for his contention that the Earth was not the center of the Universe, studied fossils(evidence of past life) and concluded that they were real and not inanimate artifacts. James Hutton, regarded as the Father of modern geology, developed the Theory of Uniformitarianism, the basis of modern geology and paleontology. According to Hutton's work, certain geological processes operated in the past in much the same fashion as they do today, with minor exceptions of rates, etc. Thus many geological structures and processes cannot be explained if the earth was only a mere 5000 years old.

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Radiometric age assignments based on the rates of decay of radioactive isotopes, not discovered until the late 19th century, suggest the earth is over 4.5 billion years old. The Earth is thought older than 4.5 billion years, with the oldest known rocks being 3.96 billion years old. Geologic time divides into eons, eroas, and smaller units. An overview of geologic time may be obtained athttp://www.ucmp.berkeley.edu/help/timeform.html.

Figure 3. The geologic time scale, hilighting some of the firsts in the evolution of life. One way to represent geological time. Note the break during the precambrian. If the vertical scale was truly to scale the precambrian would account for 7/8 of the graphic. This image is fromhttp://www.clearlight.com/~mhieb/WVFossils/