The Scientific Method

"*Science walks on two feet - theory and experiment. Sometimes it is one foot which is put forward first, sometimes the other, but continuous progress is made only by the use of both*." Robert Millikan - 1923

The primary aim of science is to find the truth - truth for its own sake, regardless of its possible practical use or application. Truth and knowledge elevates human life, so one could say that the "spirit" of science is that of good will. Science is performed by and for humans and answers questions of interest to us. It's also a common property of man, having been created by peoples of many different cultures over time.

Because science touches many aspects of our lives, we should have some acquaintance with its structure and operation. Science is organized knowledge which devises concepts and laws helping us to understand the world around us, and gives an accurate description of how it works. It gives a prediction of occurrences in nature which is accurate nearly 100% of the time. Because science is subject to change as our collective knowledge increases, it is thus self-correcting and provisional, and progress is often based on showing that what we believe today can be shown to be wrong, or at least incomplete tomorrow.

Science is defined not as what we know, but rather how we came to know something.

During the past four centuries a "scientific method" has been developed to help find answers we have about the natural world. This "data-based explanation" of some phenomena is at the core of scientific discovery. It takes problems and searches for the best solution, irrespective of unbiased interest and prejudices, and with uncompromising honesty. Therefore, scientists do not make decisions based on religious faith, financial rewards, or self-preservation. At the core of the scientific method is that no statement can be accepted without solid evidence, and this is the foundation on which modern science is built. One can not accept statements unsupported by data, and this in turn is what distinguishes science from pseudoscience and dogma.
So that the scientific method is "data driven," and the importance of data can not be understated.

This method of observation, data interpretation, hypothesis, testing, and theory are described briefly below.

observations & experiments

All observations involve using our five senses. Being that our senses have limitations we can extend our senses with the use of instruments. The development of the telescope extending our sense of sight is an example. Observations entail observing nature without manipulating it, while experiments manipulate nature, and we observe the outcome. For example, in astronomy distant objects can only be observed, while a physicist in a laboratory can create a device, change the conditions of operation, and watch what happens. Or a chemist can alter the conditions of reacting substances by changing the concentration or temperature of the reactants.

Experimentation is central to scientific investigation, and an experiment contains two main elements; design and analysis of data. Being there is an interplay between experimental design and data analysis (and that no experiment can be preformed without some error) one must determine with what degree of certainty the data gathered supports a particular hypothesis. Experimental design can only be learned through trial and error.

hypothesis

In trying to explain observed facts one puts forward a supposition, or what we call a "hypothesis." It's a tentative, but completely definite point of view which is adopted for the sake of argument. This educated guess must be supported by observations or experiments. If this educated guess leads to conclusions which are in accord with observations or experiments, then the hypothesis becomes an important part of a theory.

ex; Ptolemy observed the celestial sky and believed that the earth was at the center of all motion ("geocentric model"), and although wrong, it did satisfy requirements of a scientific hypothesis, as it;

- was based on observational facts
- explained all celestial motions known at the time
- could make predictions of future positions of celestial bodies with considerable accuracy

predictions & testing

Any hypothesis needs to be tested by making predictions. Do experiment outcomes agree with the predictions? Without the ability test ideas by future observations or experiments the scientific method does not function. Nothing can be accepted as a scientific fact unless it is testable. Tests do not always prove or disprove ideas, but rather can describe the conditions under which they are valid.

ex; Aristotle, a great observer of the natural world and whose ideas were the last word for many centuries to come, claimed that "a big stone falls faster than a small one." What is remarkable about this statement is not that it is wrong, but that it never occurred to Aristotle to test it. He may have taken such a suggestion as an insult. Why resort to such action when the mind could answer all questions? Unfortunately this mind-set made it impossible for Aristotle to pick up two stones to observe which one fell faster or even take data. More unfortunate is that this mind-set continued into the 16th century.

repeatable experiment - Because all physical laws are the same for observers, it is convincing when the results of testing can be reproduced by other investigators. Knowing the conditions and instruments by which results were deteremined, can the same results be obtained? This "repeatability" is best arrived at when variables can be controlled, and thus replication of results is more complete.

theory & law

Once a set of basic principles has been established by testing, and future predictions can be realized, a theory develops. It is a statement which comes from given facts and logical reasoning, and should also be able to account for exceptions or deviations. If a scientific hypothesis or theory has been tested again and again without contradiction it can become scientific law. A scientific law (principle) is a description of constant relationships between certain kinds of phenomena. These descriptions can be in the form of a mathematical relation or in sentence form.

Theories are always subject to change or refinement as new facts emerge from future experiments. These new facts (which are not absolute or immutable) either support the theory, prove it to be incorrect, or under what circumstances it is valid. So the beauty of the scientific method is that it's self-correcting.

In regards to the lessons we have learned from the history of science, *"it teaches us, in effect, that the actual state of our knowledge is always provisional and there must be, beyond what is actually known, immense new regions to discover."* Louis de Broglie - 1957