Thinking scientifically

A major feature of science, which distinguishes it from other human activities, is its reliance upon shareable experiences, logical rigor, unambiguous and measurable predications, reproducibility, consensus building, and the (hopefully) cheerful acceptance that our understanding of the world is incomplete and likely to remain so.

The scientific method involves gathering information, building models that make testable, quantifiable predictions, and testing those models through experiment and careful observation.

In some cases, this can lead to a reconsideration of "the facts" on which the model was based, or the revision of the model, which is then tested again. Sometimes models just don't work and new models have to be devised.

> Scientific knowledge is a body of knowledge of varying degrees of certainty-some most unsure, some nearly sure, but none absolutely certain ... Now we scientists are used to this, and we take it for granted that it is perfectly consistent to be unsure, that it is possible to live and not know."- Richard Feynmann

> Ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science.- Charles Darwin.

Watch – Murray Gellman: On beauty, truth, and physics

Listen to – Alan Sokal: Sense About Science lecture

Tentative scientific models, known as hypotheses, are valuable and valid only in as much as they make testable predictions about the phenomena they purport to explain.

As scientific models become more sophisticated, these predictions must become more and more accurate and generalized.

An important feature of a good model is the rule of thumb, known as Occam's Razor, namely that all other things being equal, the simplest explanation is the best.

> The aim of science is not to open the door to infinite wisdom, but to set the limit to infinite error. - Bertol Brecht.

> it is the business of history to distinguish between the miraculous and the marvelous ... to reject the first ... and doubt the second. - David Hume.

Through their predictions, scientists are able to determine whether a particular model accurately describes the observable world. If not, something must be missing or perhaps the model is partially or completely wrong.

Models are continually being modified, expanded, or replaced to make them more accurate and to explain more phenomena. A model that has been repeatedly confirmed and covers lots of observations is known as a theory.

Theories can evolve (and sometimes become extinct). Typically, when one theory is replaced by another, the new theory explains all that was encompassed by the older theory and more, and its predictions are more accurate.

For example, Newton's theory of gravity was replaced by Einstein's theory of general relativity.

In biology, there area small set of well established theories that underlie modern biology..

- The Physicochemical Theory of Life
- The Cell Theory of Life and
- The Theory of Evolution

Science is social: At its heart, science works because it involves an interactive community of scientists who keep each other (in the long run) honest. Observations, hypotheses and conclusions are presented to the public in the form of scientific papers, where their relevance and accuracy can be evaluated, more or less dispassionately, by others.

This process leads to a evidence-based, scientific consensus. Certain ideas and observations (such as The Cell Theory) are so well established that they can be reasonably accepted, whereas others are extremely unlikely to be true (such as the possibility of perpetual motion or "free energy" machines), and so can be safely ignored. In general practice, it is a waste of time and energy to doubt the former, or seriously consider the latter.

At the same time, it is possible for a single person to challenge and change accepted scientific understanding. That is not to say that it is easy to change the way scientists think; after all, most challenges to well established theories are wrong, and it is generally a waste of time to think about them seriously.

That means that a new way of looking at a phenomena must be clearly superior, both in terms of accuracy and explanatory power, to the ideas that it wishes to displace. It must explain more than the old ideas, and it must resolve problems that the older ideas were unable to adequately explain.

It is this tension between consensus, conflict and resolution that drives scientific understanding forward, so that, in the end, more and more phenomena become explicable and predictable.

Through its fundamental ability to accept change, science has come to provide the practical knowledge needed to manipulate and understand the material world.

That said, it is certainly the case that many if not most scientific ideas are quite hard to believe or accept [link], they are seriously counterintuitive. The idea that the earth is rotating at ~1000 miles an hour (at the equator) and is traveling through space in a helical path around the sun, which itself is moving [link], that at matter behaves as both a wave and a particle and that everything is made of ~100 types of atoms, created at the big bang and with stars over the course of billions of years, and that all organisms on earth (including mushrooms and people) share a common ancestor.

Science forces us to accept these as facts, because they provide a coherent and logical explanation of the world as we observe it, assuming that we observe it scientifically.

Watch the Feynman video and answer the questions below

Questions to answer

1. Based on the Gell-Mann talk, why is "beauty" in science important?
2. What does "Occam's razor" have to do with scientific beauty?
3. Based on the Sokol talk, when should we trust scientific pronouncements?

Questions to ponder

- How does the social nature of science make it different from religion (or is it)?
- Does the inability to measure something unambiguously make it unreal?
- Can ideas that do not make unambiguous and measurable predictions about the world be scientific?

- Does it matter whether science ever attains the “ultimate truth” about the world?