# How Science is an Evidence-Based Way of Knowing

By Jim MacAllister

There are many ways of knowing -- artistic, emotional, religious and others -- all valuable and important to living a meaningful life filled with a rich variety of experiences. Science is a particular way of knowing that uses a rigorous approach to evaluating evidence as the basis for making statements, creating models, exercising control of natural processes and prediction of results. This paper takes a look at how science determines what is evidence and how that is used to make models or theories describing nature.

> "Science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe.
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> Contemporary science is typically subdivided into the natural sciences, which study the material universe; the social sciences, which study people and societies; and the formal sciences, which study logic and mathematics. The formal sciences are often excluded, as they do not depend on empirical observations. Disciplines which use science, like engineering and medicine, may also be considered to be applied sciences." – Wikipedia

## What is scientific knowledge?

Science can be done by anyone with a sound mind regardless of his or her nationality, language, race, gender, sexual preference, creed, religion or atheism. Science *does require faith*, but it is faith that nature is knowable through empiricism, the idea that knowledge of nature comes through our senses, either directly or via technical equipment, and is based on, concerned with, or verifiable by: observation, experience, and measurement. Science does not claim to know the absolute Truth. Scientific knowledge is based on the best evidence available. Scientific debates are generally about what constitutes the best evidence and what conclusions can be drawn based on that evidence.

## Using Inductive Logic to Form Provisional Models

Formal sciences that use deductive logic and mathematics are certain, universal, necessary and timeless. Natural scientific knowledge is different in that it is most often acquired by inductive reasoning that works from many particular instances towards general principles. No matter how accurate and precise natural scientific knowledge might be, it can always be improved — and even disproved and replaced. Therefore, natural science is particular, relative and corrigible, or put another way, scientific models are provisional until new and better models are developed based on new evidence. Although scientific models are provisional, they are very accurate and precise approximations that match observations.

That scientific models are provisional is a strength, not a weakness because science avoids rigid dogmatic explanations that can't be changed. Martin Brasier, an Oxford scientist, defined science as "a unique system for the measurement of doubt." He emphasized that science judges not only evidence for but also evidence against alternate explanations. So while scientific knowledge may not be absolute, it has been shown to have the least doubt about its veracity. In this way, both evidence and the minimization of doubt are used to judge the most reliable way of knowing when it comes to describing, predicting and providing control of natural phenomena. Our modern world with its constant innovation and technology based in science is testimony to the power of science.

### What is a Scientific "Theory"?

The word "theory" in common vernacular is used as synonymous with a guess, but in science, the word theory is a statement about nature based on what is already known. A theory provides a framework for research and predicts certain results. A theory has to be testable in ways that will support it or demonstrate that it is false. Theories and models are maps constructed to help us understand natural phenomena, but the map is not the territory, the forecast is not the weather, and a theory is not the phenomenon it attempts to explain. We all, scientists included, need to remind ourselves that models and natural phenomena are different things. For example, money and wealth are not the same thing. It can be easy to confuse money with wealth, but money is only a medium of exchange. If you could not exchange money for something tangible and necessary, such as food, clothing, or shelter, it would be worthless.

### Minimizing Bias

We tend to favor our own ideas and often hold uninformed opinions. Most of us tend to notice evidence that supports our point of view and reinforces our cherished beliefs. Scientists are not immune from these prejudices, but there is a strong motivation to prove or falsify one's own ideas. Supporting an idea that does not hold up under scrutiny is very bad for a career in science, while pointing out error in someone else's study enhances a scientist's reputation. It is much better to find the flaws in one's own work before someone else does. This ability to look for both the pros and cons is called critical thinking.

Scientists also use critical thinking to maintain a balance between skepticism and open-mindedness. In a scientific way of knowing, we need to avoid the *temptation of certainty*, the notion that any answer represents an end to investigation. As an example of this, it was thought that all DNA in a genome is coded for making proteins. When non-protein coding DNA was discovered, it was labeled "junk DNA" and assumed to be a sort of fossil that did nothing. A scientific approach is humble and avoids naming and explaining until there's sufficient evidence for making statements. We now know that over 80% of "junk DNA" has uses.

Scientists recognize that as humans they too are susceptible to *implicit bias* that could tilt results even when they are doing their best to be objective. Consequently, their studies and experiments employ "blinding" whenever possible to eliminate this bias. Scientists also employ controlled experiments. When an experiment manipulates (e.g. moves, heats, stimulates), a variable under test, the outcome is compared with a *control*, the same experiment where the variable has not been so manipulated. In a blinded experiment, a scientist evaluates data from the manipulated and the control sample without knowing which is which.

### Reductionism and Systems Approaches: Strengths and Shortcomings

There are two primary methods used in science: reductionism and systems. Each has its own strengths and shortcomings. Reductionism reduces, or takes apart, a complex system or phenomenon into parts or pieces and then studies them independently. Sometimes a model of the object of study is substituted for the actual phenomenon in order to make disassembly and reassembly possible. This examination of components is a strategy that yields a great deal of useful information about the various parts of the process. When those parts are reassembled, an understanding of how the complex whole functions can be gained that would have been extremely difficult or impossible to achieve from observing the actual phenomenon. Most of our modern world of scientific knowledge, technology and innovation is based on the reductionist method of study.

Systems science attempts to study the system as a whole or a model of the system. The complexity and dynamics of systems can obscure observation or make measurement difficult. Our ability to study whole processes or systems, such as the weather, has been very limited until the advent of modern technologies and super computing. Now, we can model, study, measure and predict highly complex systems that were once thought to be chaotic. Systems are "more than the sum of their parts." The *more* is not a thing, rather it is the system's emergent properties, such as its autonomous organization, performance, dynamics, and interrelationships.

Reductionism utilizes our talent for reducing whole systems to arbitrary parts in order to simplify our study and understanding. However, reductionism is limited in the answers it can provide. When a whole system is reduced to parts, it is easy to begin to think of a dynamic process as an assembly of static things. A system requires all of its parts and none can be privileged, whereas reductionism can lead to certain parts being thought to be of more importance or mistaken as being the active cause of the system. Dynamic processes or systems have emergent properties, but these often vanish when a whole is imagined and studied as parts, or overlooked in the design of a model.

Natural science requires a balance of both of these approaches, reductionism and systems science, to produce the best and most complete models and understandings of nature.

**Primary Science Publishing, Peer Review, and Reproducibility**

The results of studies are reported in a primary science journal after undergoing a process of peer review by a group of scientific experts in the field. The report, or paper, must meet rigorous guidelines for discussion, citation of references, the materials and methods used, the results, including the margins of error, and what conclusions are drawn. Peers examine the paper for errors and omissions in the science and in the researchers' conclusions. It is the journal's and reviewers' reputations that are at stake when a paper is published. The scientific community then evaluates the paper and repeats the experiments using the same materials and methods as described in the paper, to see if the same results are obtained in a separate laboratory.

**Science Reporting**

Scientific reporting in popular media of all kinds can be done well, or badly; sometimes it is sensationalized or misreported. Sometimes space or time is so limited that important details are omitted and the full story isn't told. In short, scientific and medical reporting in popular media is not scientific literature. The same can be said for Wikipedia and other popular online reference sites. Even when using reputable secondary sources, it is possible that the information is out-ofdate or new research is missing leading readers to form fallacious opinions. Whenever possible, primary sources are preferred and take precedence over secondary sources.

## Conclusion

Science as a way of knowing has had a profound influence on how we create models of the world, the technologies we've developed, the way we live our lives, and our prospects for the future. This discussion covers a few important principles for understanding an evidence-based scientific world view, but there are many others. As with other ways of knowing, it is difficult or impossible to understand deeply and appreciate science for its mindset, methods, metaphysics and nuances without serious study and practice of the discipline itself.