What Is Science?

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"Science" is a term that is widely used but surprisingly poorly understood. Herein we attempt to convey some understanding of what science is.

The Top-down (Social) View

From the *top-down* point of view we ask: What is this social activity called "Science"?

Science is a *worldwide game* that is played according to a set of generally agreed-upon rules. The purpose of the game is to discover interesting or useful stories about our environment.

Science is not defined by its participants or by its subject matter, but by its process, i.e., how the game is played. Here are the main elements of the game.

1. The players are called *scientists*.
2. The *scientific literature* is a network of publications that the players use to communicate with each other. (If science were a board game, the literature would be the board with its pieces.) There are many forms to this literature. The official form is the set of *refereed journals*, but there are many important but less formal forms such as textbooks, web sites, research reports, unrefereed publications and private communications, including letters, walks down the hall, phone calls, and email.

The Bottom-up (Individual) View

One definition of science is this: Science is whatever scientists do. The bottom-up view then asks: What distinguishes a scientist from any other person? The answer lies not in the person's credentials but in his behavior.

Being a scientist means having a particular approach to finding things out. Scientists are human, therefore not necessarily consistent in all their behaviors. No scientist acts like a scientist all the time. So we're limiting our description to those moments in people's lives when they *do* behave like scientists.

In other words, it is not strictly correct to say: "Ms. X is a scientist." Rather, one should say: "Ms. X *behaves like* a scientist in her approach to this particular problem." So anyone can act like a scientist in specific situations. But we usually take a shortcut and say "Ms. X is a scientist" when Ms. X behaves like a scientist *in her public life*, that is, when she is publicly claiming competence, for example, when she is delivering a speech or publishing a paper.

Being a scientist, and therefore being a participant in the game, requires having a particular personal ethic regarding "truth". A scientist will minimize the importance of assertions about the world based solely on belief or authority or personal conviction, or even careful reasoning, and instead says: "*Let's go find out*".

A scientist insists that the only way to be able to make general statements about a phenomenon follows from studying that phenomenon by careful, reproducible observation. When you say: "Y is such-and-such" Ms. X the scientist might reply: "Oh yeah?" She will take you seriously if you say: "I (or somebody else) inferred this from careful observation of Y" but she won't take you seriously if you say: "I saw it in this book."

How the Game is Played

The most elegant statement I have seen of how scientists play the game of science was made in an article in *The New Yorker* about the philosopher Karl Popper.[1] I'll just quote it here. (The emphases and insertions are mine. The context is about how scientists might deal with the assertion: All swans are white.)

> Science, Popper proposed…didn't proceed through observations confirmed by verification; [on the contrary,] it proceeded through wild, overarching conjectures, which generalized "beyond the data" but were always controlled and sharpened by *falsification*, by refutation, by the single decisive experiment, or swan [observation]. It was the conscious, purposeful search for falsifications, and the survival of theories in the face of them, that allowed science to proceed and objective knowledge to grow.
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> In the real world, as Popper knew perfectly well, the response of the scientist who has proposed that all swans are white when a black swan appears is not to say, cheerfully, "'Wrong again!" It is to say, "You call that a swan?" The principle of falsification would begin an argument rather than prove a point. But the argument *was* the point. The argument that the black swan would produce—an argument about what evidence was crucial,

> and why—was different from all other kinds of argument. Science wasn't a form of proof. It was a style of quarrelling. The reason science gave you sure knowledge you could count on was that it wasn't sure and you couldn't count on it. Science wasn't the name for knowledge that had been proved true; it was the name for guesses that could be proved false.

The game of science *is* the quarrel. Science is not about knowledge and certainty; *science is a special process for dealing with ignorance and uncertainty*.

Theory And Experiment

The game advances when scientist A proposes a general principle (often called a *hypothesis*), then scientist B finds evidence that contradicts A's hypothesis, then C takes A's hypothesis and refines or modifies it so that B's findings will no longer contradict it. (Maybe refining it is hopeless; then the hypothesis just gets dropped.)

A hypothesis, after surviving a good amount of this testing and modification, evolves into a *theory*. A theory is a story we tell ourselves that helps us feel that we "know" more than would be the case without the theory. (Example: All swans are white.)

What does it mean to know more? Our new knowledge should enable us to make predictions that we couldn't make before: if you do such-and-such then so-and-so will happen. (No matter how hard you try, you won't find a swan that isn't white.)

A theory must be *falsifiable*; that is, it must be possible to design and execute an *experiment* one of whose possible outcomes contradicts the theory. (Go find a nonwhite swan.) Furthermore, such an experiment must be *reproducible*; that is, the design of the experiment must be such that other scientists must be able to reproduce the experiment and obtain similar results.[2] (If X claims to have found a nonwhite swan, X must show it to reliable witnesses; better yet, somebody else must be able to do what X did to find his own nonwhite swan.) If an experiment can't be reproduced, people will stop thinking about it as a candidate for falsifying the theory. But if it can reproducibly falsify the theory, that's interesting, because then the theory needs to be fixed or abandoned.

> Some theories can be so useful that they will survive a small amount of falsification. In fact, a blemish in a theory can help to direct research into trying to improve it in its area of weakness. For example, Einstein's and Newton's theories of gravitation do not quite agree. The disagreement led astronomers to concentrate their observations on certain phenomena--specifically the

bending of light rays by gravity--that ultimately showed where Einstein's predictions were more accurate than Newton’s. The predictions of Newton’s theory are excellent approximations to the results given by Einstein’s theory in the circumstance that the gravitational field is not too strong. So, under that circumstance, Newton’s theory is still used because it is simpler.

All this having been said, it is important to remember that much important experimentation is little more than hacking around in order to gain insight into a poorly understood phenomenon. It is this kind of experimentation that can so fruitfully give rise to the “wild, overarching conjectures” (i.e., hypotheses) mentioned in the Popper article.

The arrival of a new theory stimulates ideas for new experiments that might falsify it. If one of these experiments succeeds in falsifying the theory, then we are confronted with a challenge to fix the theory or to come up with another one. These are the moves of the game of science. The time interval between major moves can vary from weeks to decades, even centuries.[3]

This understanding of science provides a way for us to deal with the following matter of current controversy. Paleontologists and others frequently find dateable fossils in geologic layers such that the older fossils are in the deeper layers. If this relationship does not hold, then they expect to find evidence of a geologic event that scrambled the layers. These scientists hold the theory that this relationship is related to the deposition of the layers over a span of geologic time, during which the animals or plants that created these fossils lived and died on the surface of a particular layer. Some other people who call themselves creationists hold that all the layers and fossils were created the same week, and that the relationship between the depths of the geologic layers and the characteristics of the fossils that permit dating is completely the result of God’s design at the time of creation. If we are to deal with this assertion scientifically, we don’t ask: “Is is true?” Instead we ask: “How might we find evidence that will demonstrate it to be false?” The answer to this latter question, it is safe to say, is: “We can’t”. Therefore the creationist proposition cannot be viewed as a scientific hypothesis but must be seen as something else, external to science. This reasoning (and not somebody’s wisecrack) makes the term “creation science” an oxymoron. *Notice that the matter of the truth or validity of the creationist proposition never even comes up.*

The Human Element

Belief has no direct role in the game of science. Of course scientists, being human, can believe strongly that their theories are "true". But belief itself plays no role in the game, except possibly to speed things up by motivating a scientist to work extra hard to find some way to defend a favorite theory that is under attack (or to attack a theory being advanced by a competitor). So when someone says to you: "I do [or don't] believe in the theory of evolution", check your nonsense gauge before reacting to that statement in the expectation that you are going to have a discussion about evolution.

We live partly inside and partly outside a world view created by science. In some domains of discourse we take for granted that it's pointless to keep arguing about something when it is possible to just *go and find out*. And if there is no way to find out, then it is obvious that the argument is futile. In other domains of discourse, that idea doesn't occur to us. (Or if it does occur to us and we strongly assert it, we can find ourselves in trouble.[4])

The scientific world view is a very young phenomenon in human history. Historians generally agree that the game of science and the *let's go find out* world view got started as a self-perpetuating cooperative activity around the time of Galileo Galilei four hundred years ago, and has been going for a period of time less than ½% of the time that our species has been on Earth.[5] In other words, we are not wired up for scientific behavior. There is no reason to be confident that it is now permanent and won't disappear. As far as we know, all of human history, past, present, and perhaps future--except for this short, slender thread we call "science"--is a history of human behavior ungoverned by the rules (or even by an awareness of the rules) of science.

Notes

[1] Adam Gopnik, "The Porcupine: A pilgrimage to Popper", *The New Yorker*, April 1, 2002, pp. 88-93.

[2] "Cold Fusion" was an interesting recent case in which the matter of reproducibility was unsettled for a while. It's a lesson in how messy the game sometimes gets. http://www.its.caltech.edu/~dg/fusion.html .

[3] An excellent history of over three centuries of such exploration of the nature of electricity and magnetism is found in http://maxwell.byu.edu/~spencerr/phys442/history.pdf .

[4] Example: Spanish Inquisition, Salem Witch Trials, Hearings of the House Unamerican Activities Committee.

[5] It has been said, and is probably still true, that the majority of all scientists in all of human history are still alive.