THE NATURE OF SCIENCE

What do I mean by "science"? The term means many things to many people. To me, science is three things simultaneously—all three being inextricably intertwined.

1. Science is a system of belief. It is a way of looking at the totality of the universe. It is a way of evaluating what I can sense for myself. It is a system for evaluating what I can reason for myself. It offers a method for evaluating what others choose to tell me about the nature of things. Above all, it is a system for answering the question: "What should I believe?"

2. Science is an organized body of knowledge. It is the writings and utterances of fellow scientists, organized and presented in ways which those scientists (and others) thought appropriate at the time. It contains both ideas that have stood the test of time and attacks by fellow scientists, and ideas that have failed those tests and fallen by the wayside of scientific progress. Sometimes it is hard to tell the difference between the two.

3. **Science is a method of evaluating hypotheses.** The Scientific Method is not the only method for the generation of ideas on how thing work. Actually, many scientists give credit to intuition for the initial generation of their ideas. However, it is far and away the very best method for the much more important task of the rigorous testing of those ideas. The testing process can be brutal and is not always fair. Many brilliant scientists have been broken by the process. In the long run, however, the scientific method of testing hypotheses works and works well.

Science as a System of Belief

People who study how we believe things have divided all systems of belief into four general categories: intuition, revelation, authority, and evidence. Science, as a system of belief, only accepts the last of these categories, evidence; and places severe restrictions on what it considers to be scientific evidence.

Scientific evidence consists of an observation of the natural world or an observation of the results of a scientific experiment. Each scientific discipline has its own set of strict rules and procedures for making an observation. This observation must be made by a rational human being, and must be capable of being duplicated by a minimum of two independent investigators. As more and more independent investigators obtain the same results, the scientific evidence becomes stronger.

Opinions by any authorities, no matter how renowned, do not constitute scientific evidence. Intuition, no matter how perceptive, does not constitute scientific evidence. Revelations from God, no matter how exalted, do no constitute scientific evidence. Only observations and experiments, independently corroborated, constitute scientific evidence.

It should be noted here that “evidence” in the legal sense—that is, in a court of law—is not the same as scientific evidence. They are completely different concepts, with completely different philosophical frameworks. For example, expert testimony can constitute legal evidence, but is not considered scientific evidence. On a somewhat different note, the results of mathematical models are not considered scientific evidence. Such models deal with hypothetical and ideal situations (“what if . . .”), and not with the real world.

Most of us end up believing the basic tenets of whatever religion we were brought up in. Many scientists are devoutly religious, but they are very careful to strictly compartmentalize their beliefs. When it comes to morals, ethics, and social behavior, they follow the teachings of their religion. When it comes to their professional work, they follow the rules of scientific evidence.

Science is an Organized Body of Knowledge

Most of what we call knowledge today is scientific knowledge. The scope and depth of this knowledge is almost beyond the ability of the human mind to comprehend, and this scope and depth increases almost daily and at rates that approach the exponential.

Luckily, this knowledge is organized (after a fashion) into disciplines, fields, sub-fields, sub-sub-fields, and so on down to minutiae. New fields are being created everyday in response to the need—perceived or real. Specialists are becoming more and more specialized. The old joke used to be that: a scientist was somebody who studied more and more about less and less, until—finally—he knew absolutely everything about absolutely nothing. The joke is becoming the reality.

Tens of thousands of doctoral dissertations are written every year. Each is supposed to deal with something new and different. What usually results is that the scholar breaks off a small piece of his already narrow specialty and studies it to death. What are really needed, and what are becoming more and more difficult to find, are competent generalists—people who can cross scientific boundaries or stand back far enough to grasp several areas of specialization and see patterns that nobody else has seen.

When such people do come along, they become giants in their fields, and their work often results in entirely new ways of looking at the natural world. God send us more of them!

Science is a Method of Evaluating Hypotheses

You, as a scientist look at your world and see something interesting. "Hmmm," you mutter, "that's peculiar. I wonder why it's doing ***that***. Could it possibly be . . . ?" And a new hypothesis is born.

The first thing you do is to check the scientific literature to see if your hypothesis is really a new one or an old one that has been rejected for some good reason or other. If nobody else has come up with that hypothesis before, you begin to get excited. You get the very pleasurable sensation that maybe—just maybe—you are on to something.

The next step is to gather evidence bearing on the observed phenomena. You can't collect evidence without a hypothesis to frame it with, because everything in the universe is evidence for or against something (usually many somethings), and you have only a single lifetime—and not all of that.

After you have gathered as much evidence as your time and abilities permit, you examine the hypothesis to see if it explains the evidence. If it does, and if it does it better than any other current hypothesis, you begin to get a nice warm fuzzy feeling about the world in general and your particular place in it.

You then proceed to write up both your hypothesis and the evidence. This writing follows very strict procedural constraints. You have to follow the rules that exist in your profession and in the journals that publish in your profession. This can easily be more work and much more difficult that the actual scientific investigation. Finally, you submit your article to a professional journal, and sit back and wait. And wait. And wait.

The editors of the journal will evaluate your article in terms of its substance, style, and significance. They will then send it off to what are called “referees”. These are recognized experts in the particular field of your article. Custom usually calls for three referees, but there can be either more or fewer. These referees read your article, and write evaluations of its merit. These evaluations are (eventually) sent to the journal. If they are more or less unfavorable, the journal will send your article back to you with their bland, polite, and uninformative regrets.

If the evaluations are encouraging, then the article is considered for publication sometime in the future. Exactly when depends upon how many other articles they have in the hopper. The editors will also consider such mundane matters as to how much space they have in any particular issue, how to get an interesting mix of subject material, and so on.

Once the article actually appears in publication, the fun begins. Every other scientist in your field goes over what you have said with the intellectual equivalent of an electron microscope. Any previous work on the subject that you failed to cite in your article will be brought immediately to your attention, with the implication (valid or not) that it had something significant and relevant to say on the subject matter of your article, and that your failure to properly cite the work implies faulty scholarship on your part.

Every statement in your article will be scrupulously examined. Any infelicities of phrasing will be seized upon and criticized. Your every observation will be examined for proper methodology and technique. Your every interpretation will be scrutinized as to whether alternative interpretations might have been made—and might have been better justified by the evidence. All of these criticisms will be carefully delineated in letters to the Editor, which will then be published in future issues of the Journal.

You will get your chance to respond, of course, but your response will be given the exact kind of critical evaluations that your original article provoked.

Thus, the road to scientific progress is littered with wrecked and abandoned hypotheses, and lined with whimpering investigators. But it does go on. Science progresses by destroying current hypotheses, using new observations and experiments. It then forges new hypotheses that are in better keeping with both the old evidence and the new. Nothing is sacred, nothing is off limits, and no one is proof from attack. And nothing is ever, ever "proven". It is always subject to the eventual and certain disproof of new discoveries. The scientific method is not a method for "proving" anything. It is a method for disproving ideas and suggesting—not proving—better ones.

Hypotheses, Theories, and Laws

Scientific beliefs as to why or how some natural phenomenon occurs can be divided into three categories: hypotheses, theories, and natural laws. These differ from one another in terms of how much acceptance they enjoy in the scientific community, and how many exceptions each has.

1. Hypotheses. Hypotheses are the lowest form of scientific explanation. They are simply tentative explanations offered to explain some bit of behavior of the natural world. They may be offered tepidly or enthusiastically, held by a single investigator or by thousands, been conceived just this morning or centuries ago.

What they are, are ideas waiting for evidence to either support them or disprove them. If you should ask some scientist whether he or she accepts a particular hypothesis, you will probably get an answer along the lines of, "It has some merit, but it obviously requires further investigation."

"It requires further investigation" is a scientific mantra. Everything—I mean everything—requires further investigation. Skeptics will say that it simply reinforces job security; but, in all honesty, it is an essential core concept of science.

The accumulation of evidence will either support a hypothesis or negate it. A hypothesis is never proven; it simple gathers more and more support. Eventually, most of the scholars in a given field might accept it as the best explanation of a number of competing explanations. At that point, it may be said to gain the status of a theory.

2. Theories. Theories are scientific explanations that are generally accepted by the majority of serious scholars in a particular field. This does not mean that they believe them implicitly and without reservation. Scientists know that—like hypotheses—theories are subject to steady erosion and almost continual change, and may well have to be abandoned completely in future years, as new evidence accumulates.

Theories also have broader applications than most hypotheses. They explain a much greater range of observations and experiment. They often form the basis for an entire discipline. The theory of continental drift became the basis for the discipline of plate tectonics. Mendel's theory of heredity underlies almost all of today's biological sciences—most specifically that of genetics. Newton's theory of gravitational attraction has gained the status of a natural law.

3. Natural Laws. Natural laws are explanations for natural phenomena that have either no known exceptions or none of major significance. They are usually expressed in mathematical form. They form the basis for all of the physical sciences, including the atmospheric sciences. There are thousands of them. They are usually named after the person who first proposed them or elucidated them. Seminal scientists, like Newton, have dozens of laws bearing their name. The world of science can bestow no higher honor.

Summary: Science, more than anything else, is a way of looking at the natural world and evaluating its behavior. It tries to be rational, objective, independent, and open to new ways of looking at things. It quite often succeeds.

Scientists (as opposed to science itself) are first and foremost human beings. We are prone to see things the way we've always seen them, are reluctant to embrace new ideas, frequently believe things despite evidence to the contrary, are awed by eminence, follow the crowd, and generally behave pretty much as our fellow human beings.

Every once in a while, however, one of us will rise above all that. And the world is never again the same. There is hope yet for us all.