Sailing From Genoa

Some thoughts on methods of discovery and the history of science

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This month the *Scientific* presents two articles dealing with the history of science and medicine. The study of the historv of science has become very popular in recent years, and this is not surprising. More than ever, events are being shaped not only by men and ideas, two of the traditional "prime movers" in history, but also by technological and scientific advances. An understanding of the development and normal processes of science is therefore an integral part of understanding history in general. Furthermore, as a discipline in itself, the history of science often provides an exciting view of man as he interacts with his environment. Most significantly, an understanding of the history of science provides the raw material out of which the philosophers of science can form a theory of science, leading to an understanding of how scientific theories are conceived and accepted, and how scientific revolutions are formulated and won.

From a simplistic point of view, a full understanding of how scientific theories are formulated would in principle allow future scientists to formulate better theories faster. One could therefore envision a scientist armed with a knowledge of how creative advances are made in his field capable of making dramatic progress using a strategy based on that knowledge. The goal of a "super scientist" is not without its seekers. Several groups of philosophers and logicians are currently attempting to formalize inductive logic (the generalization of a particular to general rules), much as deductive logic (the derivation from general rules facts about specific instances) has been formalized. The goal of the work is to be able to use a specific set of observations (for example, that twelve emeralds have been observed, and each of them is green) to induce a general law (therefore, all emeralds are green), and to be able to assign a probability that the conclusion will be true based on the amount and type of evidence adduced in support of that conclusion. The attempt to do this has been hampered by many difficulties and paradoxes, but it suffices to say that most of those attempting to understand scientific advances are attempting to attain less ambitious objectives.

Most of these objectives involve the attainment of a reasonably qualitative model of how science works. These models vary in formality and complexity; some subtlely underlie the discussion of science and science history found in the mass media and high school science textbooks. Others have been the centerpieces of lengthy treatises and the focal point of heated arguments among philosophers. A few of the more popular models are listed below, with an appropriate example.

March of Science: This model views science as a progression of discoveries and events leading inexorably to the attainment of a particular goal. It presupposes that the investigators making the discoveries are aware of their goal and orient their actions towards reaching it. Thus, to be a more effective scientist, this model would suggest that the individual select a goal (e.g., the cure of cancer) and sit back and let events take their course. Such a goal-oriented model implies that the most effective scientist is the one with the clearest perception of the directions of the future. Establishment of the proper goal is the crucial phase in scientific advances according to this theory. (This is the approach usually conveyed in high school biology classes and in media renditions of scientific discoveries.)

> *example:* Columbus, had he followed this model, might have said to his wife before leaving Spain: "Don't hold dinner for me, dear, I'm off to discover America."

Revolutionary Science: One of the most popular models for scientific advance was recently proposed by Thomas Kuhn. Kuhn argued that the "paradigm," variously defined as the conglomeration of beliefs, theories, and assumptions which are accepted at any given time, create the fundamental basis of "normal" science. Normal science is characterized by experimenters using the prevailing paradigm, and designing experiments to solve scientific problems which evolve from or involve the paradigm. Kuhn distinguishes normal science from "revolutionary" science, which occurs when enough evidence has accumulated that contradicts the paradigm. The crisis condition that is created as frightened scientists realize that the assumptions they have held for years are crumbling around them leads them to attempt defining a new theory that overturns old theories, and resolves the crisis.

Whereas the "March of Science" model predicts a smooth flow for science, the revolutionary model of Kuhn predicts discontinuities. Even though evidence for the new paradigm was obtained while employing the old paradigm, and so some continuity is present, statement of the new pardigm creates a break with previous normal science. Once the new paradigm is accepted, normal science can continue. The break in the flow of science is clearly seen in the inability of a person who only understands the old paradigm to comprehend at all the ideas of the new paradigm. (For example, variability of length and mass with velocity could not be comprehended by one who understood only Newtonian mechanics.)

example: "You see dear, the current paradigm in geography is that the world is flat, yet we have these problems: when ships sail over the horizon, the ship body disappears before the sails disappear; the sun strikes the earth at different angles; and so on. These facts have created a crisis among the geographers here, so don't hold dinner, I'm off to discover America."

Context of Justification Model: Over the past several decades, one of the most popular ways of analyzing scientific discoveries has been to ignore the actual process of "discovery" (which was considered to result by accident or by other irrational processes) and concentrate instead on analyzing how the theory became accepted by, or justified to, the scientific community. The set of data, or "context" of justification, was presumed to fit into a tidy logical packet. A theory was tested by running experiments, the results of which the theory predicted. Should the experimental results be inconsistent with the predictions made by the theory, the theory would be discarded. The two primary difficulties with this model is first, that it gives the scientist no idea how to formulate theories in the first place, and second, it is inconsistent with history, since there have been many instances in which a theory was tenaciously adhered to despite substantial counter-evidence.

example: Don't hold dinner for me dear. I'm off to test the theory that the world is round, and so I am sailing west. If the world is round, I should reach India. If I don't reach India, I will discard my idea that the world is round." (Case in point: Columbus, although he did not reach India, did not discard his theory. He merely named the New World inhabitants Indians.)

Socio-Economic Model: In an attempt to understand better the motivations of the scientists who make discoveries, many have suggested the importance of sociological and economic factors. Thus, scientists are viewed as individuals motivated not necessarily by an inner drive to ascertain the truth, but by attempts to gain recognition and fame, fortune, or even tenure.

example: "The Bank of Genoa has just foreclosed on my loan. I've got to get tenure at the University of Pisa, and I cannot afford to sail East to India. My economic solvency requires that I believe that my world is round. Therefore, dear, if you expect me to pay for dinner, don't wait up. I'm sailing west to India."

Bumbling Scientist Model: (from Webster: bumbling—self-important in a blundering sort of way) This model implies that scientists often pick the wrong goals, but find out the "right" things; that they start out looking for the right things in the wrong way, but stumble onto the proper way; and that they sometimes find out the right things, but are unable to properly interpret them. The natural world, according to the model, is too complex for man to properly understand and approach it.

example: "I have a hunch that the world is round, dear, and that means that India is just over the western horizon. Therefore, dear, hold dinner for me, I am sailing west to India and expect to be back in a half hour."

As the reader reads the articles devoted to the history of science in this issue and subsequent issues, he will be able to decide for himself which, if any, of these models he feels best describes scientific advance. Perhaps he will find, as we have, that no single model is satisfactory—that all are applicable in different circumstances—and that much work and thought is needed before a completely acceptable, unified theory of science is developed.