The Scientific Method

A Useful Fiction

Over the course of human history, people have developed many interconnected and validated ideas about the physical, biological, psychological, and social worlds. These ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment. The modes of inquiry used to develop these ideas employ special ways of observing, thinking, experimenting, and validating. These modes of inquiry represent a fundamental aspect of the nature of science, and reflect how science tends to differ from other modes of knowing. This study aid is designed:

1. To offer a definition of science;
2. To identify the primary theoretical elements of the scientific method; and,
3. To describe the scientific method in actual practice.

I. The Nature of Science

It is easy as students to become so engrossed in memorizing the results of the scientific enterprise--the facts-, terminology, issues, theories, etc.-- that we fail to grasp or appreciate the overall activity or process of the scientific enterprise. Scientists make two assumptions about the physical universe. First, they presume that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study. Second, they assume that the universe is a vast single system in which the basic rules are everywhere the same. In other words, scientists assume that those factors, which caused certain effects yesterday, will also cause those same effects today or tomorrow. With these assumptions in mind, we can offer the following definition of scientific activity:

Science is that human activity which attempts to describe, explain, and predict by the use of good empirical evidence the way the physical universe works.

This definition emphasizes several important features of science. First, it is based on the description or observation of data. As important as is the collection of data, science, in the second place, seeks to explain this data by identifying cause-and-effect relationships among these data. Proposed explanations are referred to as hypotheses. Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data. Third, if the observations are accurate and the explanations are correct, and then science should be capable of reliable predictions. Explanation and prediction is critical to science because it permits humans to produce desired~ events and prevent undesired events. Thus, science is a process of producing knowledge. The process depends both on making careful observations (descriptions) of phenomena and on inventing hypotheses (explanations) for making sense out of those observations.

II. Scientific Method in Theory

In attempting to clarify the special nature of the scientific method, scientists have identified a series of activities. Scientists, from time to time, will find themselves engaged in activities such as:

(1) Observing and classifying data;
(2) Formulating problems relevant to the data;
(3) Suggesting hypotheses or possible explanations for the problem;
(4) Performing mathematical or statistical calculations;
(5) Deducing testable implications from each possible solution;
(6) Designing experiments to verify or falsify these implications;
(7) Experimenting under controlled conditions (when possible); and,
(8) Generalizing from the observed results of these experiments.

These steps are listed in a logical rather than a chronological order. A given scientist can occasionally begin at different points. And some scientists even specialize ill certain steps.

Regardless of where they begin or focus, sooner or later, the validity of scientific claims is settled by referring to observations of phenomena. To make their observations scientists use (a) their own senses, (b) instruments that enhance or expand those senses (such as microscopes or telescopes), and (c) instruments that tap characteristics quite different from what humans can sense (such as infrared light or magnetic fields).

III. Scientific Method in Practice

The theoretical understanding of the scientific method is a *useful fiction.* You will seldom, if ever, see all of these stages exhibited in any single scientific enterprise. Scientific inquiry is not easily described apart from the context of investigations in particular sciences. There are numerous reasons for this difficulty. First, the ever-increasing complexity and diversity of science makes it hard to perceive clearly the general features of the scientific enterprise. We become too preoccupied with the facts, ideas, and theories to see the method of science. Second, the sciences differ significantly among one another. Certain sciences, such as archaeology or history, focus on collecting and interpreting data while conducting few if any experiments. And some scientists, such as a theoretical physicist, may spend most of their time performing mathematical calculations.

In actual practice there simply is no fixed set of steps that all scientists always follow, no one path that leads them unerringly to scientific knowledge. In some circumstances, for example, scientists can control conditions deliberately and precisely to obtain evidence and conduct experiments. Often, however, control of conditions may be impractical (as in studying stars or volcanoes), unethical (as in studying humans), likely to distort the natural phenomena (as in studying wild animals in captivity), or impossible (as in studying history).

From time to time scientists may be seen exploring the characteristics of a naturally occurring process (like Aristotle's study of the embryology of chicks), exploiting an accident (like Pasteur's preparation of artificial vaccines), utilizing mathematical methods (like Eratosthenes' calculation of the earth's circumference), deciding between rival hypotheses (like Lorenz's work on the conditions of imprinting), using models to research otherwise unresearchable processes (like Freibourg's study on the cause of the rainbow), or reacting to null results (like Michelson and Morley's work on the impossibility of detecting the motion of the earth).

And yet, in all these very different instances, scientists were employing the scientific method and producing knowledge, which contributed to our increasingly comprehensive and reliable understanding of our physical environment and ourselves.

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