(i) The cognitive structure of science

Scientific knowledge is organized in a hierarchical system, referred to by philosophers as the "cognitive structure" of science. First there are facts, such as a botanist may collect in observing the offspring of plant-breeding experiments, or a physicist in measuring the properties of subatomic particles. From the facts, a scientist will try to formulate a guess, or hypothesis, that explains some particular feature of the facts. The hypothesis must be tested by experiment, and preferably by one that will give a clear-cut corroboration or disproof. The back-and-forth procedure between hypothesis and experiment—getting an idea and testing it out—is a major part of what is known as the scientific method.

When a hypothesis has been confirmed a sufficient number of times, it may take on the character of a law, such as the law of gravity or the laws of Mendelian genetics. Laws are valued principles in science because they predict and account for large bodies of facts. They describe important regularities in nature. But they don't necessarily explain the facts they describe. The law that chemicals combine with each other in fixed proportions doesn't explain why this is the case but simply states the regularity. For explanations, it is necessary to go to the deeper-level structures called theories.

A theory in science has a much more solemn meaning than in everyday language. A theory makes sense of and explains a vast body of scientific knowledge, including both laws and the facts dependent on the laws. The theory is of course supported by the facts and laws it explains, but at the same time it often contains elements for which there is no immediate proof. These elements, or inferred entities, are usually a critical working part of the theory, despite their unverified status. The atomic theory of matter explains Dalton's law of fixed proportions, but at the time the theory was formulated and for long afterward, there was no direct evidence for the existence of atoms. Genes were first posited in theories about genetics long before their physical nature

was discovered. The theory of evolution is another example of a theory highly valued by scientists because of its enormous explanatory power, but which lies in a sense too deep to be directly proved or disproved.

The cognitive structure of science extends from the plethora of observable facts, to the underlying laws which account for them, to the theories which explain the laws. An important feature of the structure is its flexibility. The laws can be changed or modified in the light of new facts, and the theories are liable to be toppled by revolutions in thought that replace them with better and usually more comprehensive theories. The structure of scientific knowledge is constantly expanding. It grows by generating new hypotheses, or predictions from theory, and exploring for new facts to bring into the domain of its explanatory systems.

(ii) The verifiability of scientific claims

Science is a public activity, conducted by a community of scholars who probe and verify each other's work. A scientist must pass a series of tests which begin when he applies through the "peer review system" (described below) for funds to conduct a research program. He must publish the results of his research in a scientific journal, but before publication his article is sent out by the journal editor to scientific reviewers, known as referees. The referees advise the editor as to whether the work is new, whether it properly acknowledges the other researchers on whose results it depends, and most importantly, whether the right methods have been used in conducting the experiment and the right arguments in discussing the results.

A scientific claim has thus passed through two checks for reliability before it is published. Once in the open scientific literature, it is subject to a third and more exacting test, that of replication. A scientist who claims a new discovery must do so in such a way that others can verify the claim. Thus in describing an experiment a researcher will list the type of equipment used and the procedure followed, much like a chef's recipe. The more important the new discovery, the sooner will other researchers try to replicate it in their own laboratories.

Scientific knowledge thus differs from other forms of knowledge because it is verifiable. It is produced by a community of scholars who constantly check each other's work, weeding out the unreliable, building on the corroborated results. Science is a community of scholars engaged in the production of certifiable knowledge.

(iii) THE PEER REVIEW PROCESS

Most university science is funded by the federal government, the dominant patron of basic research. The government sets the overall amount of funds to spend in each area, but it is committees of scientists who decide which of their colleagues should receive the money. The committees, which are advisory to government agencies, constitute the "peer review system." Consisting of fellow experts in the field, they judge the merit of detailed grant applications submitted by their colleagues. By the decisions of the peer review committees, funds are channeled to those with the best ideas and the clearest evidence of ability to carry them out.

This is the complex of ideas and values that constitutes the prevailing ideology of science. It is the way science should, and does in part, work. Scientists are by and large so powerfully wedded to this ideology that they find it hard to see significance in any deviations from it. Yet the ideology is an imperfect description of how science works in practice. It derives from the studies of science undertaken particularly by philosophers, but also by historians and sociologists. These specialists have seen reflected in science the features and ideals of special interest to their own disciplines and have quite studiously ignored all others. Simply put, the philosophers have written solely about the logic of science, the sociologists have been interested only in the "norms" of scientific behavior, and the historians for the most part have been concerned to demonstrate the progress of science and the heartening triumph of rationality over superstition.

The conventional ideology of science is a composite picture

drawn from the findings of all three disciplines. But since each has described science from its own special perspective and ideals, the composite picture is, not surprisingly, a somewhat incomplete and idealistic representation. That is why there is no room in the picture for scientific fraud, or indeed for many other important aspects of the scientific process.

Where the conventional ideology goes most seriously astray is in its focusing on the process of science instead of on the motives and needs of scientists. Scientists are not different from other people. In donning the white coat at the laboratory door, they do not step aside from the passions, ambitions, and failings that animate those in other walks of life. Modern science is a career. Its stepping-stones are published articles in the scientific literature. To be successful, a researcher must get as many articles published as possible, secure government grants, build up a laboratory and the resources to hire graduate students, increase the production of published papers, strive to be awarded a tenured post at a university, write articles that may come to the notice of committees that award scientific prizes, gain election to the National Academy of Sciences, and hope one day to win an invitation to Stockholm.

Not only do careerist pressures exist in contemporary science, but the system rewards the appearance of success as well as genuine achievement. Universities may award tenure simply on the quantity of a researcher's publications, without considering their quality. A laboratory chief who has skillful younger scientists working for him will be rewarded for their efforts as if they were his own. Such misallocations of credit may not be common, but they are common enough to encourage a certain evident cynicism.

It is in the climate of cynicism that a scientist's mind may first turn to considering the previously unthinkable: that of embellishing the research results he reports. Fraud in science is of course the abnegation of a researcher's fundamental purpose, the search for truth. It is thus an act of considerable moment, and one that is unlikely to be taken without careful consideration of the prevailing attitudes and mores in the laboratory, as well as of the chances of getting caught.

The term "scientific fraud" is often assumed to mean the wholesale invention of data. But this is almost certainly the rarest kind of fabrication. Those who falsify scientific data probably start and succeed with the much lesser crime of improving upon existing results. Minor and seemingly trivial instances of data manipulation—such as making results appear just a little crisper or more definitive than they really are, or selecting just the "best" data for publication and ignoring those that don't fit the case—are probably far from unusual in science. But there is only a difference in degree between "cooking" the data and inventing a whole experiment out of thin air.

A continuous spectrum can be drawn from the major and minor acts of fabrication to self-deception, a phenomenon of considerable importance in all branches of science. Fraud, of course, is deliberate and self-deception unwitting, but there is probably a class of behavior in between where the subject's motives are ambiguous even to himself. Cases of self-deception are included in this book because they pose exactly the same test to the self-policing mechanisms of science as errors committed deliberately.

Science is considered here as a unity, in other words with no formal distinction made between its different disciplines. We doubt that there are serious differences among the ways that physicists, biologists, or sociologists go about their work. All are following the scientific method and share the same goals; only the substance of their concerns is different. The study of fraud sheds light on how all scientists behave; nevertheless, its incidence appears to be somewhat less in the "hard" sciences, i.e., those such as physics, which have a high mathematical content. The tight logical structure of mathematics virtually precludes falsification, so that highly mathematized sciences possess a certain built-in protection against fraud. In the spectrum that runs from hard sciences to soft sciences, from physics to sociology, the center is probably occupied by biology, a discipline in which fraud is by no means rare. Biology and medicine are also the disciplines in which fraud is likely to affect the public welfare most directly.

What is it about the structure of science that makes fraud possible? What features in the sociology of science make fraud

tempting and often profitable? How can a person who has undergone the lengthy training to become a scientist even consider faking data? The answers to questions such as these suggest a picture of science considerably different from that of the conventional ideology.