SEVEN

Science and Its Pretenders

The scientific method is the most powerful tool we have for acquiring knowledge. By its means we've discovered the structure of the atom and the composition of the stars, the causes of disease and cures for infection, the blueprint for life and the mechanisms of growth. Use of the scientific method is not confined to scientists, however. Whenever we try to solve a problem by systematically evaluating the plausibility of various solutions, we are proceeding scientifically. To improve our problem-solving ability, then, it's useful to know what's involved in conducting a scientific investigation.

Scientists use the scientific method to acquire knowledge about the nature of reality. Many people don't think of science as a search for the truth, however. Instead, they think of it as a means for creating commodities. When they think of science, they think of such things as televisions, VCRs, and CDs.
Although scientific knowledge is used in the manufacture of these items, the production of such goods is not the goal of science. Science seeks to understand the general principles that govern the universe—not to produce gadgets.

Gadget production is the province of technology, which applies scientific knowledge to practical problems. The line between science and technology is often difficult to draw, because the same persons may engage in both pursuits. Scientists, in conducting their investigations, may fabricate special apparatus, while technologists, in designing their mechanisms, may perform systematic experiments that lead to scientific discoveries. In general, however, we may say that science produces knowledge while technology produces goods. Scientists are primarily interested in knowing how something works while technologists are primarily interested in making something that works. The best indication for scientists that they know how something works is that they can successfully predict what it will do. Thus science seeks to understand the world by identifying general principles that are both explanatory and predictive.¹

**SCIENCE AND DOGMA**

It's tempting to say that what distinguishes science from all other modes of inquiry is that science takes nothing for granted. But this statement is not strictly true, for there is at least one proposition that must be accepted before any scientific investigation can take place—that the world is publicly understandable. This proposition means at least three things: (1) The world has a determinate structure; (2) we can know that structure; and (3) this knowledge is available to everyone. Let's examine each of these claims in turn.

If the world had no determinate structure—if it were formless and nondescript—it couldn't be understood scientifically because it couldn't be explained or predicted. Only where there is an identifiable pattern can there be explanation or prediction. If the world lacked a discernible pattern, it would be beyond our ken.

But a determinate structure is not enough for scientific understanding, we also need a means of apprehending it. As we've seen, humans possess at least four faculties that put us in touch with the world: perception, introspection, memory, and reason. There may be others, but at present, these are the only ones that have proven themselves to be reliable. They're not 100 percent reliable, but the beauty of the scientific method is that it can determine when they're not. The scientific method is self-correcting, and as a result it is our most reliable guide to the truth.²
Science versus Technology

Unfortunately, technology has given science a bad name in some quarters. Although technology is responsible for such wonders as telephones, refrigerators, and microwaves, it is also responsible for such horrors as atomic bombs, chemical weapons, and industrial pollution. Some believe that even greater horrors are lurking in the wings. For example, recombinant DNA technology, which has given us the power to create new life forms, could destroy us if we use it to create organisms that alter the ecological balance of the planet. Computer technology, which has given us the power to create intelligent machines, also could destroy us if we create machines that are smarter than we are. Of such machines, Marvin Minsky, director of the Artificial Intelligence Laboratory at MIT, has reportedly said, "Maybe, if we're lucky, they'll want to keep us around as pets." To save the human race from such ignoble ends, some people believe that the scientific research behind the technologies should be stopped. There is some knowledge, they claim, that is simply not worth having.

While the potential for disaster that these technologies pose is significant, so is their potential for good. Computer technology can help us improve our problem-solving abilities, communication systems, and manufacturing processes.

Recombinant DNA technology can be used to cure disease, solve the world's food shortage, and even clean up environmental pollution. Weighing risks and benefits is never easy. Whichever way the balance tilts, however, it's important to realize that knowledge itself is not the problem. The question is how that knowledge should be applied.

What makes scientific understanding public is that the information upon which it is based is, in principle, available to everyone. All people willing to make the appropriate observations can see for themselves whether any particular claim is true. No one has to take anybody's word for anything. Everything is out in the open, and it is open season on everything. To be accepted as true, a scientific claim must be able to withstand the closest scrutiny, for only if it does can we be reasonably sure that it's not mistaken.

SCIENCE AND SCIENTISM

Some critics of science say that far from being an impartial search for the truth, science is an imperialistic ideology that champions a particular worldview, namely, a mechanistic, materialistic, and atomistic one. This ideology is often referred to as scientism. Scientism, they claim, is committed to the view that the world is a great machine, composed of minuscule particles of matter that interact with each other like tiny billiard balls. Such a world is inimical to human flourishing because it treats us like machines. Stripping us of our dignity and humanity, it

Science is the great antidote to the poison of enthusiasm and superstition.

—Adam Smith
denies the importance of our thoughts, feelings, and desires. The devastating effects of this approach to reality, they claim, can be witnessed by anyone who turns on the nightly news.³

What we need, these critics suggest, is a different worldview, one that is more organic, holistic, and process oriented. The world should be viewed not as a giant machine composed of isolated entities, but as a giant organism composed of interdependent processes. Only by adopting this sort of worldview can we regain the social, psychological, and ecological balance necessary for continued survival on this planet.⁴

While it may be true that, at any one time, a particular worldview is dominant in the scientific community, it would be a mistake to identify science with any particular worldview. Science is a method of discerning the truth, not a particular body of truths. It is a way of solving problems, not a particular solution to them. Just as you cannot identify science with its applications, so you cannot identify it with its results. The worldviews held by scientists have changed radically over the years: The worldview of quantum mechanics is far from the mechanistic worldview of the seventeenth century.

Those critics who believe that we should adopt a more organic and holistic worldview do so on the grounds that it offers a more accurate description of reality than does a mechanistic and atomistic one. That may well be true, but the only way to find out is to determine whether there is any evidence to that effect, and the best way to make such a determination is to use the scientific method. The scientific method provides the best means of assessing competing theories.

**SCIENTIFIC METHODOLOGY**

The scientific method is often said to consist of the following four steps:

1. Observe
2. Induce general hypotheses or possible explanations for what we have observed
3. Deduce specific things that must also be true if our hypothesis is true
4. Test the hypothesis by checking out the deduced implications⁵

But this conception of the scientific method provides a misleading picture of scientific inquiry. Scientific investigation can occur only after a hypothesis has been formulated, and induction is not the only way of formulating a hypothesis.

A moment's reflection reveals that data collection in the absence of a hypothesis has little or no scientific value. Suppose, for example,

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Science is nothing but developed perception, interpreted intent, common sense rounded out and minutely articulated.

—GEORGE SANTAYANA
that one day you decide to become a scientist, and having read a standard account of the scientific method, you set out to collect some data. Where should you begin? Should you start by cataloging all the items in your room, measuring them, weighing them, noting their color and composition, and so on? Should you then take these items apart and catalog their parts in a similar manner? Should you note the relationship of these objects to one another, to the fixtures in the room, to objects outside? Clearly, there's enough data in your room to keep you busy for the rest of your life.

From a scientific point of view, however, collecting this data wouldn't be very useful because it wouldn't help us evaluate any scientific hypotheses. The goal of scientific inquiry is to identify principles that are both explanatory and predictive. Without a hypothesis to guide our investigations, there is no guarantee that the information gathered would help us accomplish that goal.

Philosopher Karl Popper graphically demonstrated the importance of hypotheses for observation:

Twenty-five years ago I tried to bring home the same point to a group of physics students in Vienna by beginning a lecture with the following instructions: "Take pencil and paper, carefully observe, and write down what you have observed!" They asked, of course, what I wanted them to observe. Clearly the instruction, "Observe!" is absurd. (It is not even idiomatic, unless the object of the transitive verb can be taken as understood.) Observation is always selective. It needs a chosen object, a definite task, an interest, a point of view, a problem.6

Scientific inquiry begins with a problem — why did something occur? How are two or more things related? What is something made of? An observation, of course, is needed to recognize that a problem exists, but any such observation will have been guided by an earlier hypothesis.7 Hypotheses are needed for scientific observation because they tell us what to look for — they help us distinguish relevant from irrelevant information.

Scientific hypotheses indicate what will happen if certain conditions are realized. By producing these conditions in the laboratory or observing them in the field, we can assess the credibility of the hypotheses proposed. If the predicted results occur, we have reason to believe that the hypothesis in question is true. If not, we have reason to believe that it's false.

Although hypotheses are designed to account for data, they rarely can be derived from data. Contrary to what the traditional account of the scientific method would have us believe, inductive thinking is rarely used to generate hypotheses. It can be used to formulate certain

How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service!
— CHARLES DARWIN

In scientific work, those who refuse to go beyond fact rarely get as far as fact.
— THOMAS H. HUXLEY
elementary hypotheses such as this one: Every fish ever caught in this lake has been a bass; therefore every fish that ever will be caught in this lake will be a bass. But it can’t be used to generate the more sophisticated hypotheses scientists commonly use because scientific hypotheses often postulate entities that aren’t mentioned in the data. The atomic theory of matter, for example, postulates the existence of atoms. All of the data upon which the atomic theory rests, however, can be described without mentioning atoms. Since scientific hypotheses often introduce concepts not found in their data, there can be no mechanical procedure for constructing them.  

Hypotheses are created, not discovered, and the process of their creation is just as open-ended as the process of artistic creation. There is no formula for generating hypotheses. That’s not to say that the process of theory construction is irrational, but it is to say that the process is not mechanical. In searching for the best explanation, scientists are guided by certain criteria, such as testability, fruitfulness, scope, simplicity, and conservatism. Fulfilling any one of these criteria, however, is neither a necessary nor a sufficient condition for being a good hypothesis. Science therefore is just as much a product of the imagination as it is of reason.

Even the most beautifully crafted hypotheses, however, can turn out to be false. That’s why scientists insist on checking all hypotheses against reality. Let’s examine how this check might be done in a particular case.

Suppose you hypothesize that a new drug is an effective painkiller. To test this hypothesis, you might prescribe the drug to a number of patients. If a majority of those who took the drug report that they feel less pain, you may think that you have a good reason for believing that it works. But actually you don’t, for the positive results you obtained may be due to the placebo effect. Since over one-third of those people who ingest a substance and believe that it is a painkiller will experience pain reduction even if the substance has no painkilling properties, you need to devise a test that will take the placebo effect into account.

One way of accounting for the placebo effect is to divide the subjects into two groups, giving one group a placebo and the other the drug. In this case, if a majority of those taking the drug report less pain while only a third of those taking the placebo do, you have somewhat better grounds for believing that the drug is an effective painkiller. But you still don’t know that it is, for the test you performed doesn’t establish its effectiveness beyond a reasonable doubt. The reason for this doubt is that the people conducting the experiment may have unwittingly influenced the results. As we saw in Chapter 3, experimenters can aff
can affect the outcome of a test by conveying their expectations to their subjects in extremely subtle ways. It's possible that the experimenters unconsciously revealed to the subjects which pills were placebos and which weren't. It's also possible that the experimenters interpreted the subject's reports in accordance with their own expectations. Until the doubts raised by these possibilities are eliminated, the drug's actual effectiveness remains unknown.

These doubts can be removed by setting up a double-blind experiment in which neither the subjects taking the pills nor the experimenters themselves know which subjects received the drug. Experimenter effects are thus reduced to a minimum. But even the successful completion of such a test would not establish the drug's effectiveness beyond a reasonable doubt, for there could be other factors at work that you haven't taken into account. Not until others have replicated your results can you legitimately claim to know that the drug is effective. Only then can you be reasonably sure that none of the things that could go wrong with an experiment did go wrong.

It should be clear from this example why the scientific method is such an effective means of acquiring knowledge. Knowledge, you will recall, requires the absence of reasonable doubt. By formulating their hypotheses precisely and controlling their observations carefully, scientists attempt to eliminate as many sources of doubt as possible. They can't remove them all, but often they can remove enough of them to give us knowledge.

Not all sciences can perform controlled experiments, because not all natural phenomena can be controlled. Much as we might like to, there's little we can do about earthquakes, volcanoes, and sinkholes, let alone comets, meteors, and asteroids. So geological and astronomical hypotheses can't usually be tested in the laboratory. They can be tested in the field, however. By looking for the conditions specified in their hypotheses, geologists and astronomers can determine whether the events predicted actually occur.

Since many legitimate sciences don't perform controlled experiments, the scientific method can't be identified with the experimental method. In fact, the scientific method can't be identified with any particular procedure because there are many different ways to assess the credibility of a hypothesis. In general, any procedure that serves systematically to eliminate reasonable grounds for doubt can be considered scientific.

You don't have to be a scientist to use the scientific method. In fact, many of us use it every day; as biologist Thomas H. Huxley realized, “Science is simply common sense at its best—that is, rigidly accurate in observation, and merciless to fallacy in logic.” When getting the right answer is important, we do everything we can to ensure...
The Duhem Hypothesis

Pierre Duhem, a French philosopher of science, was perhaps the first to realize that hypotheses cannot be tested in isolation. Harvard philosopher Willard Van Orman Quine puts Duhem's insight this way: "Hypotheses meet the tribunal of experience as a corporate body." Here's how Duhem put it:

People generally think that each one of the hypotheses employed in Physics can be taken in isolation, checked by experiment, then when many varied tests have established its validity, given a definitive place in the system of Physics. In reality, this is not the case. Physics is not a machine which lets itself be taken apart; we cannot try each piece in isolation, and in order to adjust it, wait until its solidity has been carefully checked; physical science is a system that must be taken as a whole; it is an organism in which one part cannot be made to function without the parts that are most remote from it being called into play, some more so than others, but all to some degree. If something goes wrong, if some discomfort is felt in the functioning of the organism, the physicist will have to ferret out through its effect on the entire system which organ needs to be remedied or modified without the possibility of isolating this organ and examining it apart. The watchmaker to whom you give a watch that has stopped separates all the wheel-works and examines them one by one until he finds the part that is defective or broken; the doctor to whom a patient appears cannot dissect him in order to establish his diagnosis; he has to guess the seat and cause of the ailment solely by inspecting disorders affecting the whole body. Now, the physicist concerned with remedying a limping theory resembles the doctor and not the watchmaker.⁹

CONFIRMING AND CONFUTING HYPOTHESES

The results of scientific inquiry are never final and conclusive but are always provisional and open. No scientific hypothesis can be conclusively confirmed because the possibility of someday finding evidence to the contrary can't be ruled out. Scientific hypotheses always go beyond the information given. They not only explain what has been discovered; they also predict what will be discovered. Since there's no guarantee that these predictions will come true, we can never be absolutely sure that a scientific hypothesis is true.

Just as we can never conclusively confirm a scientific hypothesis, we can never conclusively confute one either. There is a widespread belief that negative results prove a hypothesis false. This belief would be true if predictions followed from individual hypotheses alone, but...
they don't. Predictions can be derived from a hypothesis only in conjunction with a background theory. This background theory provides information about the objects under study as well as the apparatus used to study them. If a prediction turns out to be false, we can always save the hypothesis by modifying the background theory. As philosopher Philip Kitcher notes:

 Individual scientific claims do not, and cannot, confront the evidence one by one. Rather . . . "hypotheses are tested in bundles." . . . We can only test relatively large bundles of claims. What this means is that when our experiments go awry we are not logically compelled to select any particular claim as the culprit. We can always save a cherished hypothesis from refutation by rejecting (however implausibly) one of the other members of the bundle.10

To see this point, let's examine Christopher Columbus's claim that the Earth is round.

Both Christopher Columbus and Nicholas Copernicus rejected the flat Earth hypothesis on the grounds that its predictions were contrary to experience. They argued that if the Earth were flat, all parts of a ship should disappear from view at the same rate as it sails out to sea. But that's not what is observed. To someone on shore, the lower part of a ship disappears before the upper part. As a result, they concluded that the Earth must not be flat. Furthermore, they argued, if the Earth were round, the lower part of a ship would disappear before the upper part. Because this is what is observed, the latter hypothesis is the more credible one.

But if the Earth were flat, all parts of a ship would fade from view at the same rate only if light traveled in straight lines. If it traveled in curved lines, concave upward, the lower part of a ship could well disappear from view before the upper part. As a ship sailed farther out to sea, the light from the lower part would curve into the ocean before the light from the upper part did, thus making the lower part invisible before the upper part.11 So we can maintain the view that the Earth is flat as long as we're willing to change our view of the nature of light. In general, any hypothesis can be maintained in the face of seemingly adverse evidence if we're willing to make enough alterations in our background beliefs. Consequently, no hypothesis can be conclusively confuted.
In a world where light travels in curved lines, Figure C shows what we should see if a ship is close by, and Figure D shows what we should see if the ship is farther away.

It is not true, however, that every hypothesis is as good as every other. Although no amount of evidence logically compels us to reject a hypothesis, maintaining a hypothesis in the face of adverse evidence can be manifestly unreasonable. So even if we cannot conclusively say that a hypothesis is false, we can often conclusively say that it's unreasonable.

The flat Earth hypothesis, for example, is manifestly unreasonable—and yet it has defenders to this day. Although the voyages of Columbus and other seafaring explorers nearly killed the theory in the fifteenth century, it was resurrected in England in 1849 by an itinerant lecturer who called himself Parallax (his real name was Samuel Birley Rowbotham). The world, he argued, is a flat disc with the North Pole at its center and a 150-foot wall of ice—the South Pole—encircling its perimeter. According to Parallax, those who sail around the world simply travel in a big circle. What makes the lower part of a ship disappear before the upper part is atmospheric refraction and what he called the zetetic law of perspective.

Exactly what the zetetic law of perspective is is unclear. But its use by Rowbotham is instructive, for it illustrates a popular method for shielding hypotheses from adverse evidence: constructing *ad hoc* hypotheses. A hypothesis threatened by recalcitrant data can often be saved by postulating entities or properties that account for the data. Such a move is legitimate if there is an independent means of verifying their existence. If there is no such means, the hypothesis is *ad hoc*.

*Ad hoc* literally means "for this case only." It's not simply that a hypothesis is designed to account for a particular phenomenon that makes it ad hoc (if that were the case, all hypotheses would be ad hoc). What makes a hypothesis ad hoc is that it can't be verified independently of the phenomenon it's supposed to explain.

For example, by 1844, it was known that the planet Uranus didn't follow the orbit predicted by Newton's theories of gravity and planetary motion. The observed orbit differed from the predicted orbit by two minutes of arc, a discrepancy much greater than that of any other known planet. In 1845, the astronomer Urbain Jean Joseph Leverrier hypothesized that the gravitational force of an unknown planet affected Uranus's motion. Using Newton's theories of gravity and motion, he calculated the planet's position. On the basis of those
The Hollow Earth

Flat and round do not exhaust the possible conceptions of the Earth. How about hollow? The hollow Earth theory was first proposed by the astronomer Edmund Halley, the discoverer of Halley's comet, to account for various irregularities in compass readings noted by sailors. It has since become the property of cranks. Biologist Ted Schultz discusses its evolution:

In 1818, U.S. Infantry Captain John Cleves Symmes, a hero of the War of 1812, announced his revolutionary theory that the earth is a hollow shell containing four additional concentric spheres, all accessible via polar openings thousands of miles across. Symmes proposed to lead an expedition to the "warm and rich land, stocked with thrifty vegetables and animals" that lay beyond the frozen North, inside the earth. In 1828, at the urging of Symmes' follower Jeremiah Reynolds, Congress actually approved the plan. The Secretaries of the Navy and Treasury prepared three ships for the adventure, but the newly elected President Andrew Jackson put an end to the project.

If Symmes' ideas failed to inspire serious scientific investigation, they did inspire works of fiction, including Edgar Allan Poe's Narrative of Arthur Gordon Pym and Manuscript Found in a Bottle. Meanwhile, in 1869 a man named Cyrus Teed had a revelation. The earth was hollow all right but we live on the inside. Teed, who formed a religion around his theory, traveled around the country gathering followers and in 1894 he founded the Koreshan colony in Estero, Florida. Teed died in 1908, but the Koreshan colony exists to this day. A variation of Teed's idea, known as Hohluwelebre, or Hollow Earth Doctrine, was widely held in Nazi Germany.

In 1906, William Reed's contribution to hollow-earth theory, The Phantom of the Poles, appeared. Reed dispensed with Symmes' idea of concentric spheres, describing instead a single hollow globe with polar openings and an undiscovered world of continents and seas within. He explained that the aurora borealis is nothing more than the reflection of forest fires and volcanoes in the earth's interior.

In 1913, Marshal Gardner published A Journey to the Earth's Interior, or Have the Poles Really Been Discovered, followed in 1920 by an enlarged edition. While Reed had proposed that the inner earth is illuminated by sunlight penetrating through the polar openings, Gardner believed that it contains its own miniature sun, the light from which causes the auroras. He theorized that Eskimos are descended from inner-earth races, and that the mammoths found frozen in arctic ice originate there.

In 1964 Raymond Bernard's modestly titled The Hollow Earth: The Greatest Geological Discovery in History appeared. Borrowing heavily from the works of Reed and Gardner, Bernard expanded the theory to include flying saucers.

According to Bernard, the people who live in the center of the earth are the survivors of a nuclear war between the inhabitants of Atlantis and Mu (a former island continent in the Pacific). Their relocation to the center of the Earth was necessary to escape the effects of the radiation produced by the war. The UFOs we observe are really Atlantean spaceships sent from the center of the Earth to keep tabs on us surface dwellers.
calculations, he requested that astronomer Johann Gottfried Galle in Berlin search a particular region of the sky for it. In less than an hour after Galle began his search, he noticed something that was not on his charts. When he checked again the next night, it had moved a considerable distance. He had discovered the planet that we now call Neptune.

If the aberrant orbit of Uranus had not been accounted for, Newton's theory would have been in jeopardy. So Leverrier's postulation of another planet can be seen as an attempt to save Newton's theory from negative evidence. But his hypothesis was not ad hoc, for it could be independently verified. If he had claimed, however, that some unknown and undetectable (occult) force was responsible for Uranus's erratic behavior, that would have been an ad hoc hypothesis. For, by definition, there would be no way to confirm the existence of such a force.

When a scientific theory starts relying on ad hoc hypotheses to be saved from adverse data, it becomes unreasonable to maintain belief in that theory. The phlogiston theory of heat provides a case in point.

The scientific study of heat began in earnest shortly after Galileo's invention of the thermometer (or thermoscope, as he called it) in 1593. Over the years it was discovered that different substances absorb heat at different rates, that different substances change state (solid, liquid, gas) at different temperatures, and that different substances expand at different rates when heated. To explain these phenomena, German chemist Georg Ernst Stahl proposed in the late seventeenth century that all combustible substances and metals contain an invisible substance that came to be known as phlogiston.

Phlogiston was considered to be an elastic fluid composed of particles that repel one another. (This explained why things expand when heated.) These particles were thought to be attracted to particles of other substances with different strengths. (This explained why some things heat faster than others.) When particles of phlogiston come into contact with particles of another substance, they supposedly combine to form a new state of matter. (This explained why ice turns into water when heated.) Phlogiston also seemed to explain such mysteries as why a substance turns to ash when burned (it loses phlogiston); why a metallic oxide turns back into a metal when heated with charcoal (it gains phlogiston); and why pounding on a substance can make it expand (it releases stored phlogiston). Because the phlogiston theory seemed to explain so much, it became the dominant theory of heat in the eighteenth century.

It always had its detractors, however, for phlogiston was a very mysterious substance. Not only was it colorless and odorless; it was...
weightless as well. Even though phlogiston was supposed to flow into substances that were heated, careful experiments had found that increases in temperature did not produce increases in weight. Phlogiston was also thought to flow out of substances that were burned. What ultimately led to the theory's demise, however, was the discovery that some substances actually gain weight when burned. French chemist Antoine Lavoisier found that when tin was burned, for example, the resulting metallic oxide weighed more than the original tin. If phlogiston were lost during burning, he argued, this weight gain wouldn't be possible.

Defenders of the phlogiston theory tried to account for this phenomenon by hypothesizing that the phlogiston in tin possessed negative weight, so that when it was lost, the tin gained weight. But this hypothesis was soon seen for what it really was—a desperate attempt to save the theory from the facts. Unlike Leverrier's postulation of the existence of the planet that was named Neptune, there was no way to independently confirm or confute the negative weight hypothesis. It was ad hoc in the truest sense of the term.

The moral of this story is that for a hypothesis to increase our knowledge, there must be some way to test it, for if there isn't, we have no way of telling whether or not the hypothesis is true.

**CRITERIA OF ADEQUACY**

To explain something is to offer a hypothesis that helps us understand it. For example, we can explain why a penny left outside turns green by offering the hypothesis that the penny is made out of copper and that when copper oxidizes, it turns green. But for any set of facts, it's possible to devise any number of hypotheses to account for them. Suppose that someone wanted to know what makes fluorescent lights work. One hypothesis is that inside each tube is a little gremlin who creates light (sparks) by striking his pickax against the side of the tube. In addition to the one gremlin hypothesis, there is the two gremlin hypothesis, the three gremlin hypothesis, and so on. Because there is always more than one hypothesis to account for any set of facts and because no set of facts can conclusively confirm or confute any hypothesis, we must appeal to something besides the facts in order to decide which explanation is the best. What we appeal to are criteria of adequacy. As we saw in Chapter 6, these criteria are used in any inference to the best explanation to determine how well a hypothesis accomplishes the goal of increasing our understanding.

Hypotheses produce understanding by systematizing and unifying our knowledge. They bring order and harmony to facts that may...
have seemed disjointed and unrelated. The amount of understanding produced by a theory is determined by how well it meets the criteria of adequacy—testability, fruitfulness, scope, simplicity, conservatism—because these criteria indicate the extent to which a theory systematizes and unifies our knowledge.

Testability

Since science is a search for knowledge, it's interested only in those hypotheses that can be tested—if a hypothesis can't be tested, there is no way to determine whether it's true or false. Hypotheses, however, can't be tested in isolation, for as we've seen, hypotheses have observable consequences only in the context of a background theory. So to be testable, a hypothesis, in conjunction with a background theory, must predict something more than what is predicted by the background theory alone. If a hypothesis doesn't go beyond the background theory, it doesn't expand our knowledge and hence is scientifically uninteresting.

Take the gremlin hypothesis, for example. To qualify as scientific, there must be some test we can perform—other than turning on the lights—to detect the presence of gremlins. Whether there is such a test will depend on what the hypothesis tells us about the gremlins. If it tells us that they are visible to the naked eye, it can be tested by simply breaking open a fluorescent light and looking for them. If it tells us that they are invisible but sensitive to heat and capable of emitting sounds, it can be tested by putting a fluorescent light in boiling water and listening for tiny screams. But if it tells us that they are incorporeal or so shy that any attempt to detect them makes them disappear, it can't be tested and hence is not scientific.

Scientific hypotheses can be distinguished from nonscientific ones, then, by the following principle:

A hypothesis is scientific only if it is testable, that is, only if it predicts something more than what is predicted by the background theory alone.

The gremlin hypothesis predicts that if we turn on a fluorescent light, it will emit light. But this action doesn't mean that the gremlin hypothesis is testable, because the fact that fluorescent lights emit light is what the gremlin hypothesis was introduced to explain. That fact is part of its background theory. To be testable, a hypothesis must make a prediction that goes beyond its background theory. A prediction tells us that if certain conditions are realized, then certain results will be observed. If a prediction can be derived from a hypothesis and its
Falsification and Psychoanalysis

Many writers have concurred with one of Popper's assertions, which is that psychoanalysis is not a legitimate scientific theory because it can't be falsified. No observation or experimental test can show the theory to be false because psychoanalysts can always invent a just-so story to account for any possible behavior. Popper explains his dissatisfaction with psychoanalysis as follows:

The Freudian analysts emphasized that their theories were constantly verified by their "clinical observations." As for Adler, I was much impressed by a personal experience. Once, in 1919, I reported to him a case which to me did not seem particularly Adlerian, but which he found no difficulty in analyzing in terms of his theory of inferiority feelings, although he had not even seen the child... But this means very little, I reflected, since every conceivable case could be interpreted in the light of Adler's theory, or equally of Freud's. I may illustrate this by two very different examples of human behavior: that of a man who pushes a child into the water with the intention of drowning it; and that of a man who sacrifices his life in an attempt to save the child. Each of these two cases can be explained with equal ease in Freudian and in Adlerian terms. According to Freud the first man suffered from repression (say, of some component of his Oedipus complex), while the second man had achieved sublimation. According to Adler the first man suffered from feelings of inferiority (producing perhaps the need to prove to himself that he dared to commit some crime), and so did the second man (whose need was to prove to himself that he dared to rescue the child). I could not think of any human behavior which could not be interpreted in terms of either theory. It was precisely this fact—that they always fitted, that they were always confirmed—which in the eyes of their admirers constituted the strongest argument in favor of these theories. It began to dawn on me that this apparent strength was in fact their weakness.15

In making theories, always keep a window open so that you can throw one out if necessary.

—BELA SCHICK
"When Newton published his *Principia*, it was common knowledge that it could not properly explain even the motion of the moon; in fact, lunar motion refuted Newton. . . . All hypotheses, in this sense, are born refuted and die refuted." Nonetheless, we give credence to some and not others. Popper's theory is hard-pressed to explain why this is so. Recognizing that other criteria play a role in evaluating hypotheses makes sense of this situation.

**Fruitfulness**

One thing that makes some hypotheses attractive even in the face of adverse evidence is that they successfully predict new phenomena and thus open up new lines of research. Such hypotheses possess the virtue of *fruitfulness*. For example, Einstein's theory of relativity predicts that light rays traveling near massive objects will appear to be bent because the space around them is curved. At the time Einstein proposed his theory, common wisdom was that since light has no mass, light rays travel in Euclidean straight lines. To test Einstein's theory, physicist Sir Arthur Eddington mounted an expedition to Africa in 1919 to observe a total eclipse of the sun. If light rays are bent by massive objects, he reasoned, then the position of stars whose light passes near the sun should appear to be shifted from their true position. The shift should be detectable by comparing a photograph taken during the eclipse with one taken at night of the same portion of the sky. When Eddington compared the two photographs, he found that stars near the sun during the eclipse did appear to have moved more than those farther away and that the amount of their apparent movement was what Einstein's theory predicted. (Einstein's theory predicted a deflection of 1.75 seconds of arc. Eddington observed a deflection of 1.64 seconds of arc, well within the possible error of measurement.)

Thus Einstein's theory had successfully predicted a phenomenon that no one had previously thought existed. In so doing, it expanded the frontiers of our knowledge.

Since hypotheses make predictions only in the context of a larger body of background information, Lakatos prefers to talk of research programs rather than hypotheses. According to Lakatos, what distinguishes good (progressive) research programs from bad (degenerating) ones is their fruitfulness.

All the research programs I admire have one characteristic in common. They all predict novel facts, facts which had been either undreamt of, or have indeed been contradicted by previous or rival programs. . . . What really count are dramatic, unexpected, stunning predictions; a few of them are enough to tilt the balance; where theory lags behind the facts, we are dealing with miserable degenerating research programs."
The classic case of a degenerating research program, he tells us, is Marxism:

Has, for instance, Marxism ever predicted a stunning novel fact successfully? Never! It has some famous unsuccessful predictions. It predicted the absolute impoverishment of the working class. It predicted that the first socialist revolutions would take place in the industrially most developed society. It predicted that socialist societies would be free of revolutions. It predicted that there will be no conflict of interests between socialist countries. Thus the early predictions of Marxism were bold and stunning but they failed. Marxists explained all their failures: they explained the rising living standards of the working class by devising a theory of imperialism; they even explained why the first socialist revolution occurred in industrially backward Russia. They "explained" Berlin 1953, Budapest 1956, Prague 1968. They "explained" the Russian-Chinese conflict. But their auxiliary hypotheses were all cooked up after the event to protect Marxian theory from the facts. The Newtonian program led to novel facts; the Marxian lagged behind the facts and has been running fast to catch up with them.20

Marxism is a degenerating research program not only because it failed to predict any novel facts, but also because it is riddled with ad hoc hypotheses. The lesson is clear:

Other things being equal, the best hypothesis is the one that is the most fruitful, that is, makes the most successful novel predictions.

If two hypotheses do equally well with regard to all the other criteria of adequacy, the one with greater fruitfulness is better.

Having greater fruitfulness by itself does not necessarily make a hypothesis superior to its rivals, however, because it might not do as
He who proves things by experience increases his knowledge; he who believes blindly increases his errors.

— CHINESE PROVERB

well as they do with respect to other criteria of adequacy. Velikovsky's theory of Venus's genesis demonstrates this point.

In 1950 Immanuel Velikovsky published Worlds in Collision, in which he argued that many of the ancient myths depicting worldwide catastrophes can be explained on the assumption that around 1500 B.C. Jupiter expelled a glowing ball of hot gases toward the Earth. This great ball of fire, which looked to observers on Earth like a gigantic comet, was later to become the planet Venus. As the Earth passed through its tail, Velikovsky claims, showers of meteorites fell to the Earth, exploding balls of naphtha filled the sky, and oil rained from the heavens. The gravitational pull of the comet became so great that it caused the Earth to tilt on its axis and slow its rate of rotation. Cities were laid waste by earthquakes, rivers reversed their course, and a gigantic hurricane ravaged the planet. Before Venus finally settled into its current orbit, it pulled Mars off course and sent that planet hurtling toward the Earth, thus igniting a whole new wave of catastrophes.21

Since Velikovsky thought that Venus had been recently expelled from Jupiter, he predicted that it would still be hot. This prediction flew in the face of current scientific thinking, which held that Venus was cold and lifeless. The Pioneer space probe revealed, however, that Velikovsky was right: Venus is hot. At the time it was offered, then, Velikovsky's theory could claim fruitfulness among its virtues because it predicted a novel fact. Many of its other claims, however, appear to be physically impossible. Carl Sagan, for example, has calculated that the energy necessary to eject a mass the size of Venus from Jupiter is $10^{41}$ ergs, "which is equivalent to all the energy radiated by the Sun to space in an entire year, and one hundred million times more powerful than the largest solar flare ever observed."22 Velikovsky does not say how Jupiter was able to generate such energy. Nor does he explain how the Earth was able to resume its normal rate of rotation after it slowed down. Other claims conflict with well-established laws in biology, chemistry, and astrophysics.23 These laws may be mistaken, but unless Velikovsky can identify the correct laws and show that they explain astronomical events better than the currently accepted laws do, there is no reason to believe that those currently accepted laws are mistaken.

Scope

The scope of a hypothesis — or the amount of diverse phenomena explained and predicted by it — is also an important measure of its adequacy; the more a hypothesis explains and predicts, the more it unifies and systematizes our knowledge and the less likely it is to be false.
Cosmovsky's "paradigm" of which the catastrophic 400 B.C. hel. This gigantic comet passed through the Earth and caused it to rain for forty days and forty nights. In 1696, British clergyman and mathematician William Whiston published his New Theory of the Earth, in which he argued that the "chaos" from which the world developed was the tail of a large comet. The great Flood of Noah, he claimed, began on Friday, November 28, 2349 B.C. when God sent another comet that passed near the Earth and caused it to rain for forty days and forty nights. In 1882, Minnesota Irishman Ignatious Donnelly published Ragnarok, in which he argued that many of the events described in the Old Testament were the result of a comet passing close to the Earth and dumping thousands of tons of dust on it. The view that became the official cosmology of the Nazis, however, claims that our world sprang from a colossal conflagration of fire and ice. In 1913, Hans Hörbiger, a Viennese mining engineer, published Glazial-Kosmogonie, in which he argued that solar systems are formed by gigantic blocks of ice colliding with stars. Hörbiger argued that these blocks of ice follow a spiral path, so that they eventually collide with the star, causing an enormous explosion. The star ejects a molten mass of rotating matter which forms a new solar system.

Hörbiger's belief that planets follow a spiral path led him to suggest that there were originally four moons orbiting the Earth, of which our present Moon is the only remaining one. The last collision of a moon with the Earth, some 13,000 years ago, he claimed, caused the disappearance of Atlantis — the continent that the Nazis believed was the original home of the Aryan race.

Himmler was particularly impressed with Hörbiger's theories, and a treatise on the cosmic ice theory was published as one of a series of handbooks for the SA (the paramilitary wing of the Nazi Party). And Hitler himself declared that he would build an observatory in his home town of Linz, dedicated to the three great cosmologists: Copernicus, Kepler — and Hans Hörbiger.

For example, one reason that Einstein's theory of relativity came to be preferred over Newton's theories of gravity and motion is that it had greater scope. It could explain and predict everything that Newton's theories could, as well as some things that they couldn't. For instance, Einstein's theory could explain a variation in Mercury's orbit, among other phenomena.

It had been known since the middle of the nineteenth century that the planet Mercury's perihelion (the point at which it is closest to the sun) does not remain constant — that point rotates slowly, or precesses, around the sun at the rate of about 574 seconds of arc per century. Using Newton's laws of motion and gravity, it was possible to account for about 531 seconds of arc of this motion. Leverrier tried...
to account for the missing 43 seconds of arc in the same way he had accounted for the discrepancies in the orbit of Uranus—by postulating the existence of another planet between Mercury and the sun. He named this planet *Vulcan* (*Star Trek* fans take note), but repeated observations failed to find it. Einstein's theory of relativity, however, can account for the precession of Mercury's perihelion without postulating the existence of another planet. According to relativity theory, space is curved around massive objects. Since Mercury is so close to the sun, the space it travels through is more warped (again, *Star Trek* fans take note) than is the space that the rest of the planets travel through. Using relativity theory, it is possible to calculate the extent to which space is thus bent. It turns out to be just enough to account for the missing 43 seconds of arc in the precession of Mercury's perihelion.²⁵

The fact that Einstein's theory had greater scope than Newton's was a powerful argument in its favor. As the physicist P. Langevin proclaimed at the Paris Academy of Sciences:

> This theory is the only one that permits one actually to represent all the known experimental facts and that possesses moreover the remarkable power of prediction confirmed in so astonishing a manner by the deviation of light rays and the displacement of spectral lines in the gravitational field of the sun.²⁶

For Langevin, Einstein's theory is superior to Newton's because it has greater explanatory and predictive power. The principle he's relying on is this one:

> Other things being equal, the best hypothesis is the one that has the greatest scope, that is, that explains and predicts the most diverse phenomena.

**Simplicity**

Interestingly enough, even though considerations of fruitfulness and scope loomed large in the minds of many of those scientists who accepted Einstein's theory, *simplicity* was what Einstein saw as its main virtue. He wrote, "I do not by any means find the chief significance of the general theory of relativity in the fact that it has predicted a few minute observable facts, but rather in the simplicity of its foundation and in its logical consistency."²⁷ For Einstein, simplicity is a theoretical virtue *par excellence*.

Simplicity is notoriously difficult to define.²⁸ For our purposes, however, we may say that the simpler of two hypotheses is the one...
that makes the fewest assumptions. Simplicity is valued for the same reason that scope is—the simpler a theory is, the more it unifies and systematizes our knowledge and the less likely it is to be false because there are fewer ways for it to go wrong.

Since the time of Thales (arguably the West's first scientist), simplicity has been an important criterion of theory selection. To take but one example: Copernicus's heliocentric theory, which claimed that the Earth revolved around the sun, could explain no more than Ptolemy's geocentric theory, which claimed that the sun revolved around the Earth. In terms of scope and fruitfulness, then, Copernicus's theory had no advantage over Ptolemy's. In fact, Copernicus's theory had the disadvantage of being inconsistent with observed data. If Copernicus's theory were true, opponents charged, then stars nearer to Earth should seem to change their position relative to more distant stars as the Earth moved around the sun. But no such apparent change in position (known as parallax) was observed. This predictive failure did not move Copernicus and his followers to abandon the theory, however, for they believed that stars were too far away to exhibit parallax. It turns out that they were right: The nearest star is six trillion miles away. It wasn't until 1838, almost three hundred years after Copernicus's death, that stellar parallax was finally observed. (The parallax was observed when more powerful telescopes were finally available to observe stars more precisely.) Copernicus's theory, however, had long since become the accepted explanation of the structure of the solar system.

Scientists accepted Copernicus's theory in the face of such seemingly adverse evidence because it was simpler than Ptolemy's. One of the most difficult features of planetary motion to account for is the fact that certain planets, at certain times, seem to reverse their direction of...
The Ptolemaic system of planetary motion

As we've seen, hypotheses often explain phenomena by assuming that certain entities exist. The simplicity criterion tells us that, other things being equal, the fewer such assumptions a theory makes, the better it is. When searching for an explanation, then, it's wise to cleave to the principle known as Occam's Razor (in honor of the medieval philosopher, William of Occam, who formulated it): Do not multiply entities beyond necessity. In other words, assume no more than is required to explain the phenomenon in question. If there's no reason to assume that something exists, it's irrational to do so.

One of the most famous applications of this principle was made by the French mathematician and astronomer Pierre Laplace. After Laplace presented the first edition of his theory of the universe to Napoleon, Napoleon is said to have asked, "Where does God fit into your theory?" Laplace matter-of-factly replied, "I have no need of that hypothesis."
Conservatism

Since consistency is a necessary condition of knowledge, we should be wary of accepting a hypothesis that conflicts with our background information. As we've seen, not only does accepting such a hypothesis undermine our claim to know; it also requires rejecting the beliefs it conflicts with. If those beliefs are well established, the chances of the new hypothesis being true are not good. In general, then, the more conservative a hypothesis is (that is, the fewer well-established beliefs it conflicts with), the more plausible it is.31 The criterion of conservatism can be stated as follows:

Things aren't always equal, however. It may be perfectly reasonable to accept a hypothesis that is not conservative provided that it possesses other criteria of adequacy. Unfortunately, there's no foolproof method for determining when conservatism should take a backseat to other criteria.

Indeed, there is no fixed formula for applying any of the criteria of adequacy. We can't quantify how well a hypothesis does with respect to any of them, nor can we definitively rank the criteria in order of importance. At times we may rate conservatism more highly than scope, especially if the hypothesis in question is lacking in fruitfulness. At other times we may rate simplicity higher than conservatism, especially if the hypothesis has at least as much scope as our existing hypothesis. Choosing between theories is not the purely logical process it is often made out to be. Like judicial decision making, it relies on factors of human judgment that resist formalization.

The process of theory selection, however, is not subjective. There are many distinctions we can't quantify that nevertheless are perfectly objective. We can't say, for example, exactly when day turns into night or when a person with a full head of hair turns bald. Nevertheless, the distinctions between night and day or baldness and hirsuteness are as objective as they come. There are certainly borderline cases that reasonable people can disagree about, but there are also clear-cut cases where disagreement would be irrational. It would simply be wrong to believe that a person with a full head of (living) hair is bald. If you persisted in such a belief, you would be irrational. Similarly, it would simply be wrong to believe that the phlogiston theory is a good scientific theory. In general, if someone believes a theory that clearly fails to meet the criteria of adequacy, that person is irrational.