

Jacob Bronowski (1908–1974), a Polish-born intellectual, was trained as a mathematician but eventually studied and wrote on the sciences, technology, poetry, the relation between creativity in the arts and the sciences, and man's attempts to control nature throughout history. A mathematician, a literary critic, a playwright, a scientist, and an acclaimed Renaissance man, Bronowski earned an M.A. degree at Jesus College, Cambridge, England, in 1930, and a Ph.D. in 1933. His extremely wide-ranging career includes lecturing at University College in England; serving as wartime researcher for the British Ministry of Home Security during World War II, when he studied the effects of the atomic bomb; and working at multiple posts at the Salk Institute for Biological Studies in San Diego and posts at Oxford University, Massachusetts Institute of Technology, the University of Rochester, Oregon State University, Yale University, Columbia University, and the National Gallery of Art; and serving as head of projects for the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

Bronowski also worked as a British Broadcasting Corporation (BBC) commentator on atomic energy and other scientific and cultural subjects.

Bronowski came to the United States in 1964. He wrote that, after 1932, he realized it was not enough to work at a desk, was more important and what was defending human decency. It was then that Bronowski turned his attention to studying connections between art and science. Among his writings are *The Poet's Defence* (1939; retitled and reprinted, 1966); a study of William Blake (1943; retitled and reprinted, 1965); *Science and Human Values* (1965; rev. ed., 1972), his most acclaimed work; and *The Ascent of Man* (1973), essays based on a BBC television series, his most popular work. Bronowski believed that the progress of science could best be understood by recognizing the interdependence of the sciences, arts, literature, and philosophy. He emphasized the universality of human nature and the need to control violence in modern society.



The Nature of Scientific Reasoning

Jacob Bronowski

What is the insight in which the scientist tries to see into nature? Can it indeed be called either imaginative or creative? To the literary man the question may seem merely silly. He has been taught that science is a large collection of facts; and if this is true, then the only seeing which scientists need to do is, he supposes, seeing the facts. He pictures them, the colorless professionals of science, going off to work in the morning into the universe in a neutral, unexposed state. They then expose themselves like a photographic plate. And then in the darkroom or laboratory they develop the image, so that suddenly and startlingly it appears, printed in capital letters, as a new formula for atomic energy. 1

Men who have read Balzac and Zola are not deceived by the claims of these writers that they do no more than record the facts. The readers of Christopher Isherwood do not take him literally when he writes "I am a camera." Yet the same readers solemnly carry with them from their schooldays this foolish picture of the scientist fixing by some mechanical process the facts of nature. I have had of all people a historian tell me that science is a collection of facts, and his voice had not even the ironic rasp of one filing cabinet reproving another. 2

It seems impossible that this historian had ever studied the beginnings of a scientific discovery. The Scientific Revolution can be held to begin in the year 1543 when there was brought to Copernicus, perhaps on his deathbed, the first printed copy of the book he had finished about a dozen years earlier. The thesis of this book is that the earth moves around the sun. When did Copernicus go out and record this fact with his camera? What appearance in nature prompted his outrageous guess? And in what odd sense is this guess to be called a neutral record of fact? 3

Less than a hundred years after Copernicus, Kepler published (between 1609 and 1619) the three laws which describe the paths of the planets. The work of Newton and with it most of our mechanics spring from these laws. They have a solid, matter-of-fact sound. For example, Kepler says that if one squares the year of a planet, one gets a number which is proportional to the cube of its average distance from the sun. Does anyone think that such a law is found by taking enough readings and then squaring and cubing everything in sight? If he does, then, as a scientist, he is doomed to a wasted life; he has as little prospect of making a scientific discovery as an electronic brain has. 4

It was not this way that Copernicus and Kepler thought, or that scientists think today. Copernicus found that the orbits of the planets would look simpler if they were looked at from the sun and not from the earth. But he did not in the first place find this by routine calculation. His first step was a leap of imagination—to lift himself from the earth, and put himself wildly, speculatively into the sun. "The earth conceives from the sun," he wrote; and "the sun rules the family of stars." We catch in his mind an image, the gesture of the virile man standing in the sun, with arms outstretched, overlooking the planets. Perhaps Copernicus took the picture from the drawings of the youth with outstretched arms which the Renaissance teachers put into their books on the proportions of the body. Perhaps he had seen Leonardo's drawings of his loved pupil Salai. I do not know. To me, the gesture of Copernicus, the shining youth looking outward from the sun, is still vivid in a drawing which William Blake in 1780 based on all these: the drawing which is usually called *Glad Day*. 5

Kepler's mind, we know, was filled with just such fanciful analogies; and we know that they were. Kepler wanted to relate the speeds of the planets to the musical intervals. He tried to fit the five regular solids into their orbits. None of these likenesses worked, and they have been forgotten; yet they have been and they remain the stepping stones of every creative mind. Kepler felt for his laws by way of metaphors, he searched mystically for likenesses with what he knew in every strange corner of nature. And when among these guesses he hit upon his laws, he did not think of their numbers as the balancing of a cosmic bank account, but as a revelation of the unity in all nature. To us, the analogies by which Kepler listened for the movement of the planets in the music of the spheres are farfetched. Yet are they more so than the wild leap by which Rutherford and Bohr in our own century found a model for the atom in, of all places, the planetary system? 6

No scientific theory is a collection of facts. It will not even do to call a theory true or false in the simple sense in which every fact is either so or not so. The Epicureans held that matter is made of atoms 2000 years ago and we are now tempted to say that their theory was true. But if we do so we confuse their notion of matter with our own. John Dalton in 1808 first saw the structure of matter as we do today, 7

and what he took from the ancients was not their theory but something richer, their image: the atom. Much of what was in Dalton's mind was as vague as the Greek notion, and quite as mistaken. But he suddenly gave life to the new facts of chemistry and the ancient theory together, by fusing them to give what neither had: a coherent picture of how matter is linked and built up from different kinds of atoms. The act of fusion is the creative act.

All science is the search for unity in hidden likenesses. The search may be on a grand scale, as in the modern theories which try to link the fields of gravitation and electromagnetism. But we do not need to be browbeaten by the scale of science. There are discoveries to be made by snatching a small likeness from the air too, if it is bold enough. In 1935 the Japanese physicist Hideki Yukawa wrote a paper which can still give heart to a young scientist. He took as his starting point the known fact that waves of light can sometimes behave as if they were separate pellets. From this he reasoned that the forces which hold the nucleus of an atom together might sometimes also be observed as if they were solid pellets. A schoolboy can see how thin Yukawa's analogy is, and his teacher would be severe with it. Yet Yukawa without a blush calculated the mass of the pellet he expected to see, and waited. He was right; his meson was found, and a range of other mesons, neither the existence nor the nature of which had been suspected before. The likeness had borne fruit. 8

The scientist looks for order in the appearances of nature by exploring such likenesses. For order does not display itself of itself; if it can be said to be there at all, it is not there for the mere looking. There is no way of pointing a finger or camera at it; order must be discovered and, in a deep sense, it must be created. What we see, as we see it, is mere disorder. 9

This point has been put trenchantly in a fable by Karl Popper. Suppose that someone wishes to give his whole life to science. Suppose that he therefore sat down, pencil in hand, and for the next twenty, thirty, forty years recorded in notebook after notebook everything that he could observe. He may be supposed to leave out nothing: today's humidity, the racing results, the level of cosmic radiation and the stock-market prices and the look of Mars, all would be there. He would have compiled the most careful record of nature that has ever been made; and, dying in the calm certainty of a life well spent, he would of course leave his notebooks to the Royal Society. Would the Royal Society thank him for the treasure of a lifetime of observation? It would not. The Royal Society would treat his notebooks exactly as the English bishops have treated Joanna Southcott's box. It would refuse to open them at all, because it would know without looking that the notebooks contain only a jumble of disorderly and meaningless items. 10

Science finds order and meaning in our experience, and sets about this in quite a different way. It sets about it as Newton did in the story which he himself told in his old age, and of which the schoolbooks give only a caricature. In the year 1665, when Newton was 22, the plague broke out in southern England, and the University of Cambridge was closed. Newton therefore spent the next 18 months at home, removed from traditional learning, at a time when he was impatient for knowledge and, in his own phrase, "I was in the prime of my age for invention." In this eager, boyish mood, sitting one day in the garden of his widowed mother, he saw an apple 11

fall. So far the books have the story right; we think we even know the kind of apple; tradition has it that it was a Flower of Kent. But now they miss the crux of the story. For what struck the young Newton at the sight was not the thought that the apple must be drawn to the earth by gravity; that conception was older than Newton. What struck him was the conjecture that the same force of gravity, which reaches to the top of the tree, might go on reaching out beyond the earth and its air, endlessly into space. Gravity might reach the moon: this was Newton's new thought; and it might be gravity which holds the moon in her orbit. There and then he calculated what force from the earth (falling off as the square of the distance) would hold the moon, and compared it with the known force of gravity at tree height. The forces agreed; Newton says laconically, "I found them answer pretty nearly." Yet they agreed only nearly: the likeness and the approximation go together, for no likeness is exact. In Newton's science modern sciences is full grown.

It grows from a comparison. It has seized a likeness between two unlike appearances; for the apple in the summer garden and the grave moon overhead are surely as unlike in their movements as two things can be. Newton traced in them two expressions of a single concept, gravitation: and the concept (and the unity) are in that sense his free creation. The progress of science is the discovery at each step of a new order which gives unity to what had long seemed unlike. 12

Questions for Discussion

1. What is scientific reasoning? How does it differ from other kinds of reasoning?
2. Where does the erroneous image of scientists as merely reporting facts come from?
3. If science is not "a collection of facts" (Paragraph 2), what is it? Why can science not be just a collection of facts? What is a "fact"?
4. How do new scientific theories develop? How are old ideas transformed into new ones?
5. What is the purpose of science?
6. Why can good science never be purely objective? Why will pure objectivity not work? In what way should scientists be subjective?
7. Bronowski says in Paragraph 8, "All science is the search for unity in hidden likenesses." What examples does he include to illustrate that statement? What does that statement mean?

Questions for Reflection and Writing

1. Describe the process by which scientists think. Consider Copernicus and Kepler: What were their processes? How does their way of thinking still describe how scientists think today?
2. Define a type of reasoning, besides scientific, with which you are familiar. Examples might include artistic reasoning, intuitive reasoning, and historical reasoning. Describe the thinking process, providing examples from your experience, and explain how this process works.
3. Look up Leonardo da Vinci's drawing of the proportions of the body and William Blake's *Glad Day*, mentioned in Paragraph 5. Write an essay in which you explain how these drawings illustrate scientific thought. Other artworks on scientific topics could also be used in your essay.