# The Creative Process

Jacob Bronowski

## I.

Since I am a mathematician most of what I write will, in the nature of things, be concerned with the problems of creative thought in science. Nevertheless, I want at least to glance at creation in the arts also: that is, at problems in the realm of aesthetics. I should therefore begin by saying that I do not regard aesthetics as a remote and abstract interest. My approach to aesthetics as much as to scientific thought is not contemplative but active. I do not ask, "What is beauty?" or even "How do we judge what is beautiful?" I ask as simply as I can, "What prompts men to make something which seems beautiful, to them or to others?"

This is a rational question and it deserves a rational answer. We must not retreat from it into vague intuitions, or side-step it with hymns of praise to the mystical nature of beauty. I am not talking about mystics: I am talking about human beings who make things to use and to see. A rational aesthetic must start from the conviction that art (and science too) is a normal activity of human life.

All the way back to the cave paintings and the invention of the first stone tools, what moved men either to paint or to invent was an everyday impulse. But it was an impulse in the everyday of men, not of animals. Whether we search for the beginnings either of art or of science, we have to go to those faculties which are human and not animal faculties. Something happens on the tree of evolution beeween the big apes and ourselves which is bound up with the development of personality; and once our branch has sprung out, Raphael and Humphry Davy lie furled in the human beginning like the leaves in the bud. What the painter and the inventor were doing, right back in the cave, was unfolding the gift of intelligent action.

If I am to ask you to study this gift, I must point to some distinction between animal behavior and human behavior. One characteristic of animal behavior is that it is dominated by the physical presence of what the animal wants or fears. The mouse is dominated by the cat, the rabbit by the stoat; and equally, the hungry animal is dominated by the sight and smell of food, or of a mate, which make him blind to everything else present. A mastiff with food just outside his cage cannot tear himself away from the bars; the food fixes him, physically, by its closeness. Move the food a few feet away from the cage, and he feels released; he remembers that there is a door at the back of the cage, and now that he can take his eyes off the food, away he races through the door and around to the front.

This and many other experiments make plain the compulsions which hold an animal. Even outside the clockwork of his instinctive actions, his needs fix and drive him so that he has no room for maneuver. A main handicap in this, of course, is that the animal lacks any apparatus, such as human speech, by which he can bring to mind what is not present. Without speech, without a familiar symbolism, how can the mastiff's mind attend to the door behind him? His attention is free, his intelligence can maneuver, only within the few feet in which the food is not too close to the cage and is yet within range of sight or smell.

Man has freed himself from this dominance in two steps. First, he can remember what is out of sight. The apparatus of speech allows him to recall what is absent, and to put it beside what is present; his field of action is larger because his mind holds more choices side by side. And second, the practice of speech allows man to become familiar with the absent situation, to handle and to explore it, and so at last to become agile in it and control it. To my mind, the cave painting as much as the chipped flint tool is an attempt to control the absent environment, and both are created in the same temper; they are exercises in freeing man from the mechanical drives of nature.

In these words, I have put the central concept of my aesthetic: evolution has had, for man, the direction of liberty. Of course, men do at times act from necessity, as animals do. But we know them to be men when their actions have an untroubled liberty; when children play, when the young find a pleasure in abstract thought, when in maturity we weigh and choose between two ambitions. These are the human acts, and they are beautiful as a painting or an invention is beautiful, because the mind in them is free and exuberant. And you will now see why I framed my opening question so oddly; for it is not the thing done or made which is beautiful, but the doing. If we appreciate the thing, it is because we relive the heady freedom of making it. Beauty is the by-product of interest and pleasure in the choice of action.

## II.

Now I turn our attention to action in the field of science. The most remarkable discovery made by scientists is science itself. The discovery must be compared in importance with the invention of cave-painting and of writing. Like these earlier human creations, science is an attempt to control our surroundings by entering into them and understanding them from inside. And like them, science has surely made a critical step in human development which cannot be reversed. We cannot conceive a future society without science.

I have used three words to describe these far-reaching changes: discovery, invention and creation. There are contexts in which one of these words is more appropriate than the others. Christopher Columbus discovered the West Indies, and Alexander Graham Bell invented the telephone. We do not call their achievements creations because they are not personal enough. The West Indies were there all the time; and as for the telephone, we feel that Bell's ingenious thought was somehow not fundamental. The groundwork was there, and if not Bell then someone else would have stumbled on the telephone as casually as on the West Indies.

By contrast, we feel that *Othello* is genuinely a creation. This is not because *Othello* came out of a clear sky; it did not. There were Elizabethan dramatists before Shakespeare, and without them he could not have written as he did. Yet within their tradition *Othello* remains profoundly personal; and though every element in the play has been a theme of other poets, we know that the amalgam of these elements



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is Shakespeare's; we feel the presence of his single mind. The Elizabethan drama would have gone on without Shakespeare, but no one else would have written *Othello.*

There are discoveries in science like Columbus's, of something which was always there: the discovery of sex in plants, for example. There are also tidy inventions like Bell's, which combine a set of known principles: the use of a beam of electrons as a microscope, for example. Now we have to ask the question: Is there anything more? Does a scientific theory, however deep, ever reach the roundness, the expression of a whole personality that we get from *Othello*?

A fact is discovered, a theory is invented; is any theory ever deep enough for it to be truly called a creation? Most nonscientists would answer: No! Science, they would say, engages only part of the mind—the rational intellect—but creation must engage the whole mind. Science demands none of that groundswell of emotion, none of that rich bottom of personality, which fills out the work of art.

This picture by the nonscientist of how a scientist works is of course mistaken. A gifted man cannot handle bacteria or equations without taking fire from what he does and having his emotions engaged. It may happen that his emotions are immature, but then so equally are the intellects of many poets. When Ella Wheeler Wilcox died, having published poems from the age of seven, *The Times* of London wrote that she was "the most popular poet of either sex and of any age, read by thousands who never open Shakespeare." A scientist who is emotionally immature is like a poet who is intellectually backward: both produce work which appeals to others like them, but which is second-rate.

I am not discussing the second-rate, and neither am I discussing all that useful but commonplace work which fills most of our lives, whether we are chemists or architects. There were in my laboratory of the British National Coal Board about 200 industrial scientists—pleasant, intelligent, sprightly people who thoroughly earned their pay. It is ridiculous to ask whether they were creators who produced works that could be compared with *Othello.* They were men with the same ambitions as other university graduates, and their work was most like the work of a college department of Greek or of literature. When the Greek departments produce a Sophocles, or the literature departments produce a Shakespeare, then I shall begin to look in my laboratory for a Newton.

## III.

Literature ranges from Shakespeare to Ella Wheeler Wilcox, and science ranges from relativity to market research. A comparison must be of the best with the best. We must look for what is created in the deep scientific theories: in Copernicus and Darwin, in Thomas Young's theory of light and in William Rowan Hamilton's equations, in the pioneering concepts of Freud, of Niels Bohr and of Pavlov.

The most remarkable discovery made by scientists, I have said, is science itself. It is therefore worth considering the history of this discovery, which was not made all at once but in two periods. The first period falls in the great age of Greece, between 600 B.C. and 300 B.C. The second period begins roughly with the Renaissance, and is given impetus at several points by the rediscovery of Greek mathematics and philosophy.

When one looks at these two periods of history, it leaps to the eye that they were not specifically scientific. On the contrary: Greece between Pythagoras and Aristotle is still, in the minds of most scholars, a shining sequence of classical texts. The Renaissance is still thought of as a rebirth of art, and only specialists are uncouth enough to link it also with what is at last being called, reluctantly, the Scientific Revolution. The accepted view of Greece and of the Renaissance is that they were the great creative periods of literature and art. Now that we recognize in them also the two periods in which science was born, we must surely ask whether this conjunction is accidental. Is it a coincidence that Phidias and the Greek dramatists lived in the time of Socrates? Is it a coincidence that Galileo shared the patronage of the Venetian republic with sculptors and painters? Is it a coincidence that, when Galileo was at the height of his intellectual power, there were published in England in the span of 12 years these three works: the Authorized Version of the Bible, the First Folio of Shakespeare, and the first table of logarithms?

The sciences and the arts have flourished together. And they have been fixed together as sharply in place as in time. In some way both spring from one civilization: the civilization of the Mediterranean, which expresses itself in action. There are civilizations which have a different outlook; they express themselves in contemplation, and in them neither science nor art is practiced as such. For a civilization which expresses itself in contemplation values no creative activity. What it values is a mystic immersion in nature, the union with what already exists.

The contemplative civilization we know best is that of the Middle Ages. It has left its own monuments, from the Bayeux Tapestry to the European cathedrals; and characteristically they are anonymous. The Middle Ages did not value the cathedrals, but only the act of worship which they served. It seems to me that the works of Asia Minor and of India (if I understand them) have the same anonymous quality of contemplation, and like the cathedrals were made by craftsmen rather than by artists. For the artist as a creator is personal; he cannot drop his work and have it taken up by another without doing it violence. It may be odd to claim the same personal engagement for the scientist; yet in this the scientist stands to the technician much as the artist stands to the craftsman. It is at least remarkable that science has not flourished either in an anonymous age, such as the age of medieval crafts, or in an anonymous place, such as the craftsmanlike countries of the East.

The change from an outlook of contemplation to one of action is striking in the long transition of the Renaissance and the Scientific Revolution. The new men, even when they are churchmen, have ideals which are flatly opposed to the monastic and withdrawn ideals of the Middle Ages. Their outlook is active, whether they are artists, humanist scholars or scientists.

The new man is represented by Leonardo da Vinci, whose achievement has never, I think, been rightly understood. There is an obvious difference between Leonardo's painting and that of his elders—between, for example, an angel painted by him and one by Verrocchio. It is usual to say that Leonardo's angel is more human and more tender; and this is true, but it misses the point. Leonardo's pictures of children and of women are human and tender; yet the evidence is powerful that Leonardo liked neither children nor women. Why then did he paint them as if he were entering their lives? Not because he saw them as people, but because he saw them as expressive parts of nature. We do not understand the luminous and transparent affection with which Leonardo lingers on a head or a hand until we look at the equal affection with which he paints the grass and the flowers in the same picture.

To call Leonardo either a human or a naturalist painter does not go to the root of his mind. He is a painter to whom the detail of nature speaks aloud; for him, nature expresses herself in the detail. This is a view which other Renaissance artists had; they lavished care on perspective and on flesh tones because these seemed

to them (as they had not seemed in the Bayeux Tapestry) to carry the message of nature. But Leonardo went further; he took this artist's vision into science. He understood that science as much as painting has to find the design of nature in her detail.

## IV.

When Leonardo was born in 1452, science was still Aristotle's structure of cosmic theories, and the criticism of Aristotle in Paris and Padua was equally grandiose. Leonardo distrusted all large theories, and this is one reason why his experiments and machines have been forgotten. Yet he gave science what it most needed, the artist's sense that the detail of nature is significant. Until science had this sense, no one could care—or could think that it mattered—how fast two unequal masses fall, and whether the orbits of the planets are accurately circles or ellipses. By contrast, the decent hands that stitched Halley's Comet into the Bayeux Tapestry had felt in nature only for the drama.

The power which the scientific method has developed has grown from a procedure which the Greeks did not discover, for which I will retain the old-fashioned name of induction. This procedure is useless unless it is followed into the detail of nature; its discovery therefore flows from Leonardo's vision.

Francis Bacon in 1620 and Christian Huygens in 1690 set down the first intellectual bases of induction. They saw that it is not possible to reach an explanation of what happens in nature by deductive steps. Every explanation goes beyond our experience and thereby becomes a speculation. Huygens says, and philosophers have sheepishly followed him in this, that an explanation should therefore be called probable. He means that no induction is unique; there is always a set—an infinite set—or alternative hypothetical theories between which we must choose.

The man who proposes a theory makes a choice—an imaginative choice which outstrips the facts. The creative activity of science lies here, in the process of induction understood as the making of hypothetical theories. For induction imagines more than there is ground for, and creates relations which at bottom can never be verified. Every induction is a speculation and it guesses at a unity which the facts present but do not strictly imply. The most remarkable example is the periodic table of Mendeleef, and the whole theory of atomic structure which was ultimately created to explain it.

To put the matter more formally: a scientific theory cannot be constructed from the facts by any procedure which can be laid down in advance, as if for a machine. To the man who makes the theory, it may seem as inevitable as the ending of *Othello* must have seemed to Shakespeare. But the theory is inevitable only to him; it is his choice, as a mind and as a person, among the alternatives which are open to everyone.

There are scientists who deny what I have said—that we are free to choose between alternative theories. They grant that there are alternative theories, but they hold that the choice between them is made mechanically. The principle of choice, in their view, is Occam's Razor: we choose, among the theories which fit the facts we know now, that one which is simplest. On this view, Newton's laws were the simplest theory which covered the facts of gravitation as they were then known; and general relativity is not a new conception but is the simplest theory which fits the additional facts.

This would be a plausible view if it had a meaning. Alas, it turns out to be a verbal deception, for we cannot define simplicity; we cannot even say what we mean by the simpler of two inductions. The tests which have been proposed are hopelessly artificial and, for example, can compare theories only if they can be expressed in differential equations of the same kind. Simplicity itself turns out to be a principle of choice which cannot be mechanized.

Of course every innovator has thought that his way of arranging the facts is particularly simple, but this is a delusion. Copernicus's theory in his day was not simple to others, because it demanded two rotations of the earth—a daily one and a yearly one—in place of one rotation of the sun. What made his theory seem simple to Copernicus was something else: an aesthetic sense of unity. The motion of all the planets around the sun was both simple and beautiful to him, because it expressed the unity of God's design. The same thought has moved scientists ever since: that nature has a unity, and that this unity makes her laws seem beautiful in simplicity.

## V.

The scientist's demand that nature shall be lawful is a demand for unity. When he frames a new law, he links and organizes phenomena which were thought different in kind; for example, general relativity links light with gravitation. In such a law we feel that the disorder of nature has been made to reveal a pattern, and that under the colored chaos there rules a more profound unity.

A man becomes creative, whether he is an artist or a scientist, when he finds a new unity in the variety of nature. He does so by finding a likeness between things which were not thought alike before, and this gives him a sense at the same time of richness and of understanding. The creative mind is a mind that looks for unexpected likenesses. This is not a mechanical procedure, and I believe that it engages the whole personality in science as in the arts. Certainly I cannot separate the abounding mind of Thomas Young (which all but read the Rosetta Stone) from his recovery of the wave theory of light, or the awkwardness of J. J. Thomson in experiment from his discovery of the electron. To me, William Rowan Hamilton drinking himself to death is as much part of his prodigal work as is any drunken young poet; and the childlike vision of Einstein has a poet's innocence.

When Max Planck proposed that the radiation of heat is discontinuous, he seems to us now to have been driven by nothing but the facts of experiment. But we are deceived; the facts did not go so far as this. The facts showed that the radiation is not continuous; they did not show that the only alternative is Planck's hail of quanta. This is an analogy which imagination and history brought into Planck's mind. So the later conflict in quantum physics between the behavior of matter as a wave and as a particle is a conflict between analogies, between poetic metaphors; and each metaphor enriches our understanding of the world without completing it.

In *Auguries of Innocence* William Blake wrote:

> A dog starv'd at his Master's gate
> Predicts the ruin of the State.

This seems to me to have the same imaginative incisiveness, the same understanding crowded into metaphor, that Planck had. And the imagery is as factual, as exact in observation, as that on which Planck built; the poetry would be meaningless if Blake used the words 'dog', 'master' and 'State' less robustly than he does. Why does Blake say dog and not cat? Why does he say master and not mistress? Because the picture he is creating depends on our factual grasp of the relation between dog and master. Blake is saying that when the master's conscience no longer urges him to respect his dog, the whole society is in decay (is, in fact, going to the dogs). This profound thought came to Blake again and again: that a morality expresses itself in what he called its Minute Particulars—that the moral detail is significant of a society. As

for the emotional power of the couplet, it comes, I think, from the change of scale between the metaphor and its application: between the dog at the gate and the ruined State. This is why Blake, in writing it, seems to me to transmit the same excitement that Planck felt when he discovered, no, when he created, the quantum.

## VI.

In my view, the appreciation of art or mathematics or any creative act is an act of re-creation. When the man makes *you* see the unexpected likeness, makes you feel it to be natural that this likeness exists, then you in your modest way are re-creating. You re-live the act of creation; and that is why (in my view) appreciation is not passive. It is an activity of the same kind as the original act of creation, even though it is lower in intensity.

It is possible to regard creation as a special process which could express itself either in making things or in destroying them. I do not share this view. I say that the opposite of creation is not destruction but disorder. The opposite of the created work is simply chaos. And therefore, I do not agree that there is a personality which has the creative impulse in reverse, and which wants to destroy for this reason.

The act of creation is, I have said, the same in science as in art. It is a natural, human, living act. Yet, of course, a poem is obviously not like a theorem. How does it differ? That has nothing to do with how it is composed; the units differ because they match human experience in different ways. Take a theorem like the Pythagorean theorem; this is a theorem every child rediscovers. He always rediscovers it in the same form; his experience is intellectual and can be exactly matched. In the arts this does not happen. Many people are going to paint pictures with a human being and an animal, but nobody is going to paint *The Lady with the Stoat* again exactly as Leonardo did. Many people are going to write plays, not exactly like *Othello*, but on a similar theme. In the arts, it is not possible for the experience of one individual to match that of another, as if it were a blueprint. You do not read a work of art for this purpose; you re-create it, but you do not re-create the blueprint. You explore your own experience; you learn; you live; you expand inside. I have discussed these actions fully in my book *The Identity of Man.* Here I will summarize the discussion by saying that the difference between the arts and the sciences lies not in the process of creation, but in the nature of the match between the created work and your own act of recreation in appreciating it.

## VII.

One of the values which science has made natural to us is originality; as I said earlier, in spite of appearances science is not anonymous. The growing tradition of science has now influenced the appreciation of works of art, so that we expect both to be original in the same way. We expect artists as well as scientists to be forward-looking, to fly in the face of what is established, and to create not what is acceptable but what will become accepted. One result of this prizing of originality is that the artist now shares the unpopularity of the scientist: the large public dislikes and fears the way that both of them look at the world.

As a more important result, the way in which the artist pictures the world has come close to the scientist's. For example, in what I have said science is described as preoccupied less with facts than with relations, less with numbers than with arrangement. This new vision, the search for structure, is also marked in modern art.

I underline this common vision because I believe that history will look back on it as characteristic of our age. A hundred years ago the way to advance physics and chemistry seemed to be by making more and more exact measurements. Science then was a quantitative affair, and this 19th-century picture of the scientist preoccupied with numbers—the picture of Phileas Fogg at the beginning of Jules Verne's *Around the World in Eighty Days*—is still large in the popular mind.

But in fact the concern of science in our age is different: it is with relation, with structure and with shape. Today we hardly ask how large space is, but whether it is open or closed on itself. We say that rubber stretches because its atoms are strung out in chains, and a diamond does not because the atoms are locked in a closed pattern of rings. When we ask why bacteria absorb the sulfa drug on which they cannot grow, we are answered that the drug deceives them: its molecules have the same shape as the body chemical that the bacteria need. And the most arresting discovery of the 1950s was the elucidation of the geometrical arrangement by which the nucleic acid in a living cell makes copies of itself when the cell divides.

Ours is not the first age whose science is preoccupied with pattern and arrangement; Greek thought was occupied in the same way, so that Plutarch quotes it as Plato's opinion that God is a geometer. And just as Greek thought looked for the shape of things in art and in mathematics together, so our age looks for the shaping skeleton below the appearances in art as well as in science. To us the form is meaningful when it expresses the logical structure; and even in everyday things—in buildings, in airplanes and in women—we now think those shapes beautiful that, spare and direct, are dictated by the function and the structure. Certainly in works of art, what drives the best painters and sculptors today is the search for the underlying organization of nature. Unlike the Impressionists, modern painters are looking for the order below the surface, the skull beneath the skin. Abstract sculpture now often looks like an exercise in topology, exactly because the sculptor shares the vision of the topologist. And with this grand yet particular generalization, it is timely that I remind you that I am still a mathematician at heart, and that I throw open the gates of argument to the practitioners of other sciences and other arts.