SCIENCE AS TECHNOLOGY *

LEWIS MUMFORD

Research Professor of City Planning, University of Pennsylvania

THE title of this paper, Science as Technology, would not have surprised or shocked Francis Bacon, for perhaps his most original contribution to the enlargement of the province of science was his understanding of its great future role in transforming the physical conditions of life. But I am sure that the conclusions that I shall finally present—conclusions in the form of doubts, challenges, and questions—would have shocked him quite as much as it will, I fear, shock many of those who are here this morning, for his faith in science as a source of technology, and in technology itself as the final justification of science must now, after four centuries, be submitted to an historic evaluation and the pragmatic test. When Bacon's assumptions are rigorously examined, they should, I submit, lead to a modification of Bacon's original hopes and even a radical change in our own attitude toward many Baconian beliefs we have, somewhat blindly, taken to be axiomatic.

Doubtless it is natural, in celebrating Bacon's anniversary, that we should out of piety overemphasize those aspects of modern civilization that have confirmed his predictions and surpassed his none-too-cautious expectations. This is particularly true when we consider science as technology, for it is precisely in this department that his most extravagant intuitions have been realized. Three centuries before Jules Verne and H. G. Wells, to say nothing of later writers of science fiction, Bacon anticipated the multifold uses that technology would make of science.

Though Bacon was undoubtedly expressing, as a sensitive artist often does, the changing temper of his age, long before it was visible in the streets, his very predictions gave confidence in the new orientation toward the physical world as the only area in life sufficiently detached from subjective fantasies and emotional urges to serve as a common meeting ground for minds otherwise ideologically separated. Men who could not agree upon the nature of God, could come to terms by making a god out of nature, once they had hit upon a method that ruled out all experience that could not be experimentally repeated or independently verified. By following through the practical consequences of science, Bacon sought to show even those who were engaged in the most abstract calculations and experiments that they might ultimately confer greater benefits upon the race than those who were laboring to improve it by law, by morals, or by government, or who sought to change the environment solely by manual labor and art.

Now the notion that the scientific observation of air, earth, water, and fire might lead to fruitful applications in technology, must have occurred to many minds, Archimedes for one, Hero of Alexander for another, and Bacon's medieval namesake for a third, before Francis Bacon himself elaborated the idea. But Bacon helped mightily to close the gap between the spheres of science and technology, one long considered liberal but exquisitely useless, except perhaps in medicine, the other, however useful, cursed by its servile and debasing nature. Bacon held that the advancement of knowledge depended upon more than the abstract, logic-disciplined exercises of mind. He felt that science in future would rest increasingly on a collective organization, not just on the work of individuals of ability, operating under their own power; and he held, further, that instruments and apparatus were as necessary in the technology of systematic thought as they were in mining or bridge-building.

"The unassisted hand," observed Bacon, "and the understanding left to itself possess little power." This was an even more revolutionary conception than Leonardo da Vinci's aphorism: "Science is the captain, practice the soldiers"; for it implied that the captain himself had something to learn from the men in the ranks. And it was no less revolutionary, no less effective, because, from the standpoint of a mature scientific method

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it was, by overcompensation, too one-sided. Bacon's very overemphasis on the collective apparatus of science, his close concern for the operational and instrumental aspects of scientific thought, were probably needed to overcome the bias of traditional leisure-class culture, theological and humanistic, operating by choice in a social vacuum. That was a necessary contribution in his own day—as necessary as the opposite position may become in our own time.

The timeliness and significance of Bacon's contribution here should have saved him from a little of the patronizing deflation that he has been subject to in recent years. Without doubt, he was blandly indifferent to the actual procedures of successful scientists in his own time, like Gilbert and Galileo; and, further, it is no doubt true that Bacon grossly overestimated the fruitfulness of mere fact-collecting and fumbling empirical observation, though there are still areas where this kind of systematic preparatory effort yields a certain reward. By the same token, Bacon seriously underestimated, one might almost say he entirely ignored, the immense liberation that would be effected in both science and technics through the audacities of pure mathematics, dealing with possibilities and probabilities that are, until experimentally verified, outside the field of direct observation and sensory experience.

On his own terms Bacon could not and did not anticipate the sweeping transformations of the entire framework of thought effected by single minds, almost destitute of apparatus, like Newton, Clerk Maxwell, or Einstein. Even Galileo's scientific world, a world conceived solely in terms of primary qualities and measurable quantities, was almost unthinkable to Bacon. But to offset these disabilities, which plainly reduce Bacon's importance as a philosopher of science, he had a strong sense of the sociological context of science, and of the appeal that this would make to scientists, to inventors, to engineers, and to their countless human beneficiaries. He foresaw that science would become a corporate enterprise, subject to deliberate organization; and that the social goal of science, as he phrased it in The New Atlantis, would be "the enlargement of the bounds of humane empire, to the effecting of all things possible."

Curiously, what is most fresh and original in Bacon, his conception of the role of science as the spiritual arm, so to speak, of technology, is the hardest part for our contemporaries to appreciate fully today. Partly they are put off by the fact that he absurdly arrayed these new conceptions in an elaborate metaphorical court dress; but even more they are alienated, or to speak more frankly, bored, because the ideas themselves have become so engrained in our life that most of us can hardly realize that they had a specific point of origin. But if Bacon failed miserably in interpreting the methodology of science, as it was actually taking shape in his own time, he leaped ahead four centuries to the mode and milieu in which science and technics both flourish, in their peculiar fashion, today. When Benjamin Franklin founded the American Philosophical Society, he felt it necessary to stress its aim of promoting "useful knowledge": but if he had been even closer to Bacon's spirit he would have realized that usefulness is implicit in every kind of scientific knowledge, almost it would seem in proportion to its degree of abstraction and its isolation from the immediate practical concerns. The singular mission of science, as a technological agent, is to suggest uses and outlets, issuing from purely theoretic and experimental discoveries, that could not have been conceived until the scientific work itself was done.

In the past, certain branches of science, like geometry, had developed out of practical needs, like the Egyptian need for surveying anew the boundaries that had been effaced in flooded fields; and some of that interplay between practical needs and scientific investigation of course still goes on, as in the classic instance of Pasteur's researches on ferments in response to the pleas of French wine growers. But the enormous advances of science in every field have not waited for such direct stimuli, though it may very well be that they are indirect responses organically connected with the needs and purposes of our society at a hundred different points. Thus, it is quite probably not by accident that the electronics of radar location have coincided with coordinate advances in the physics and technology of high-speed flight. Increasingly, however, it is the advance of science that suggests a new technological application: indeed the technological by-products seem to multiply in direct relation to the scope and freedom of scientific research. So ready are we now to accept the inventive consequences of science that we have almost lost the safeguard of common sense or the protective device of laughter, against freaks and follies and stunts unrelated to human need, but scientifically

conceivable and technologically practicable—like the present frantic and humanly extravagant efforts to land astronauts on the moon.

Bacon's interest in the practical applications of science naturally endeared him to Macaulay and the other utilitarians of the nineteenth century, for in his *Novum Organum* Bacon boldly asserted that the "legitimate goal of the sciences is the endowment of human life with new inventions and riches." This is a more questionable goal than Bacon thought: but it is because of the accelerated fulfillment of these promises by the sciences, especially during the last half-century, that national governments and great industrial corporations have vastly augmented their financial contributions to scientific research. Bacon's merit was to make plain that there was no aspect of nature that would not lend itself to transformation and improvement through the unrestricted application of the experimental method. Necessity had always been the most reluctant mother of invention: Bacon understood that curiosity was a far more fertile parent, and that the inventions so promoted would become the mother of new necessities.

But Bacon went further: he saw that curiosity, to be fully effective, must enlist, not solitary and occasional minds, but a corps of well-organized workers, each exercising a specialized function and operating in a restricted area. By the technological organization of science as he portrayed it in the *New Atlantis,* he proposed to fabricate an engine capable of turning out useful knowledge in the same fashion that a well-organized factory would, shortly after Bacon's prediction, turn out textiles or shoes. Bacon's description of this division of labor strikes us as quaint and finicking, because of its static, ritualistic assignment of tasks; but those who would dismiss it altogether are wider of the mark than Bacon; for part of the immense quantitative output of contemporary science is surely due to its ability to make use, not only of a few great directive minds, but of a multitude of specialized piece workers, narrowly trained for their tasks, deliberately denied any individual opportunity to explore a wider field; whose part in the whole process increasingly resembles that of a factory worker on an assembly line. The corporate personality has taken over the attributes of the individual thinker; and as science comes more and more to rely for its results upon complicated and extremely expensive apparatus, like electronic computers and cyclotrons, no work along present lines can be done without close attachment to a corporate organization. The dangers that this technological advance offers to science have not yet been sufficiently canvassed; but they will perhaps nullify no small part of its rewards.

Bacon's conception of the organization of science as a technology did not altogether overlook the part played by individual creative minds: he even had a name for such seminal investigators, for he called them "Lamps," and indicated that their function was to "direct new experiments of a Higher Light, more penetrating into nature." But his peculiar contribution was to sense that, if the illuminations and insights of creative minds were to have the widest kind of application, they would need abundant collective support: state aid, corporate organization, systematic conferences and publications, liberal rewards and honors, and finally, public exhibition and celebration in museums of science and industry. It was these features of collective organization and state regimentation, not perhaps entirely unknown in pre-Christian Alexandria, that Bacon so presciently recognized, advocated, and exalted. So it was not only the Royal Society or the American Philosophical Society that Bacon anticipated: his quaint account of the future in the *New Atlantis* did ample justice to the new functions of our foundations for scientific research, and our specialized institutes and laboratories that utilize hundreds and even thousands of workers in what has increasingly become—with great rapidity since the national state itself became the main patron—factories for the mass production of knowledge, technologically exploitable and financially profitable.

In looking back over the fulfillment of Bacon's anticipations, it is plain that there were two critical points. The first occurred in the first half of the nineteenth century, when for the first time purely theoretic researches in physics, by Volta, Ohm, Henry, and Faraday, resulted, almost within a generation, in the invention of the electric telegraph, the dynamo, the electric motor; and within two generations in the invention of the telephone, the electric lamp, the x-ray, and the wireless telegraph: all of these being inventions that were not merely impracticable but technically inconceivable until pure scientific research made them live possibilities. The methods that were so fruitful in mechanics and electronics were then applied, with growing success, in or-

ganic chemistry and biology; though significantly enough the parts of technology with the longest accumulation of purely empiric knowledge, like mining and metallurgy, remained almost impervious to the advances of science.

The second critical point came during the first half of the twentieth century, along with a change of scale and magnitude partly brought about, almost automatically, by the expansion of the facilities for communication and the exploitation of new sources of power. This change lifted hitherto inviolable limits on human activities: a shot could be heard around the world by means of radio more than eleven times faster than it could be heard by the unaided ear a mile away. At this point, science itself became the technology of technologies; and as the mass production of scientific knowledge went hand in hand with the mass production of inventions and products derived from science, the scientist came to have a new status in society, equivalent to that earlier occupied by the captains of industry. He, too, was engaged in mass production.

The old image of the self-directed scientist still remains popular, particularly among scientists; but as science expands as a mass technology, the scientist himself becomes a servant of corporate organizations intent on enlarging the bounds of empire—by no means always "humane empire!" —and endowing themselves by means of invention with power and riches and worldly prestige. By this transformation the scientist has forfeited the qualities that were exalted, in the seventeenth century, as the very hallmark of the scientist—his detachment from worldly gains and his disinterested pursuit of truth. To the extent that his capacity for pursuing truth depends upon costly apparatus, collective collaboration, and heavy financial contributions from government or industry, he has lost, as Sir Charles Snow pointed out the other day, the capacity to stand alone and to say No—even on matters like the mal-exploitation of nuclear energy that threatens the future of the human race.

Not merely have the sciences, then, become technologies, but the scientist himself, caught in the corporate process, is fast becoming the model of a docile, standardized, organization man, imprisoned by his own obsolete premises, incapable of making his escape without altering those premises. I hope I need not underline the moral that Snow properly drew from this. But there is a corollary that I would stress. Since science as technology has already submitted, often with great eagerness, to political and economic pressures, for the sake of the immense scientific opportunities offered, it cannot escape facing the consequences of this submission, and actively helping to rectify them. The scientist now has the obligation of erecting intellectual and social safeguards against the frequently malign consequences of scientific discoveries, even if the creation of these internal checks and balances slow up, or occasionally bring to a halt, the process of scientific investigation or technological application. As an agent of technology, science no longer has the immunities or the irresponsibilities that it claimed for itself during its great quarrels with the Church. Today, the greatest danger to science comes not from the hostility of traditional institutions but from the patronage of contemporary ones.

Now if the fulfillment of Bacon's dream deserves our respectful recognition of his prophetic insights, it also imposes upon us a special duty—that of dissociating ourselves from the mythology he so largely helped to promote, so as to appraise, in the light of historic experience, his unexamined premises. These premises are now so thoroughly institutionalized that most of our contemporaries continue to act upon them without even a quiver of doubt. But observe: science as technology presents a series of problems that science, as the disinterested examination of nature in search of rational understanding, never confronted; for already it shows the same deep irrationalities and absurdities that mass production in other fields has brought about. The chief premise common to both technology and science is the notion that there are no desirable limits to the increase of knowledge, of material goods, of environmental control; that quantitative productivity is an end in itself, and that every means should be used to expand the facilities for quantitative expansion and production.

This was a defensible position in the seventeenth century when an economy of scarcity still prevailed everywhere. Then, each new facility for production, each fresh increment of energy and goods, each new scientific observation or experiment, was needed to make up the terrible deficiencies in consumable goods and verifiable knowledge. But today our situation is precisely the opposite of this. Because of the magnificent, awe-inspiring success of the sciences in widening the domain of prediction and control, in penetrat-

ing the hitherto inviolable mysteries of nature, in augmenting human power on every plane, we face a new predicament derived from this very economy of abundance: that of starvation in the midst of plenty. The quantitative overproduction of both material and intellectual goods poses, immediately for the Western World, ultimately for all mankind, a new problem: the problem of regulation, distribution, assimilation, integration, teleological direction. As science approximates more closely the condition of technology, it must concern itself with the machine technology's great weakness: the defects of a system that, unlike organic systems, has no built-in method of controlling its growth or modulating the enormous energy it commands in order to maintain, as in any living organism, a dynamic equilibrium, favorable to life. No one questions the immense benefits already conferred in many departments by science's efficient methodology: but what one must challenge is the value of a system so detached from other human needs and human purposes that the process itself goes on automatically without any visible goal except that of keeping the corporate apparatus itself in a state of productivity.

In science as well as in industry huge stockpiles have been accumulating which, on our present terms, cannot be adequately distributed or effectively used. There are even signs of a kind of crude valorization, with the destruction of older accumulations, through indifference or relegation to dead storage, in order to make room for current production and ensure its marketability. Our society has already reached the paradoxical state wherein our massive additions to the corpus of scientific knowledge have, through mere quantitative excess, lowered our capacity to make rational use of any part of it. In the exploding universe of science, the scattered parts are traveling at an accelerated rate ever farther from the human center. Because of our concentration on speed and productivity, we have ignored the need for integration and assimilation. The dubious morals of an acquisitive society have caught the once-disinterested promoters of science, along with their strange irrational compulsions. In practice this results in an inability to use more than a small fragment of the existing corpus of knowledge—namely that which is fashionable or immediately available, because it is being commercially exploited. This has already worked havoc in medicine, as any honest physician will tell you, and the results are visible in every other professional activity.

We are now faced, accordingly, as both Norbert Wiener and I have pointed out more than once, with the situation Goethe foresaw in the fable of the Sorcerer's Apprentice: we have achieved the magic formula for automatically increasing the supply of scientific knowledge; but we have forgotten the Master Magician's formula for regulating or halting the flood, and so are on the point of drowning in it. Science as technology gets its main financial support, and therefore its overall direction, from the national government, or from great industrial corporations like those engaged in exploiting new pharmaceutical preparations, chemical pest controls, or atomic energy, and from quasi-public philanthropic foundations exerting almost equally large powers. Though the professed aim of these organizations is truth and human welfare, they are governed in perhaps an ever greater degree by the Baconian goals of riches and power. On these premises they have no concern with ordering science in accordance with some human measure, toward the fulfillment of broader human goals: for this means altering the method of mass production and slowing down the whole process. Our schools and universities are helpless to restore an organic balance, because they themselves have accepted the same ideology and rely for a large part of their activities upon endowments that are scaled to the prospects of continued expansion and quick turnover: indeed the very possibilities for professional promotion depend more upon the number of scientific papers published than upon long-term results that may not be visible for a generation or more.

Is it not time, then, that we began to ask ourselves certain questions about science as technology that Bacon, by reason of his historic position, was too uninformed to put to himself? Are we sure that the control of all natural processes by science and techniques is by itself an effective way of relieving or improving man's estate? Is it not possible to have a surfeit of knowledge no less that a surfeit of food—with similar distress to and derangement of the organism? Have we not already evidence to show that science as technology may, through its inordinate growth, become increasingly irrelevant to any human concerns whatever, except that of the technologist or the corporate enterprise: that, indeed, as in the form of nuclear or bacterial weapons, it may

be not merely coldly indifferent but positively hostile to human welfare?

But I would go further. By what rational canon do we seek, on purely Baconian premises, to save time, shrink space, augment power, multiply goods, overthrow organic norms, and displace organisms with mechanisms that simulate them or vastly magnify some single function they perform? All these imperatives, which have become the very groundwork of science as technology in our technological society, seem axiomatic and absolute only because they remain unexamined. What rational purposes have ordained these objectives and provided us with a mechanism that has no means of self-regulation, no method of control except acceleration, and no goal except its own increase in power and authority? Is it from the standpoint of man or the machine, of the whole community's welfare or that of the corporate organization, that we accept these commitments, or fondly submit to these compulsions? Faster and faster, bigger and bigger, richer and richer, more and more inventions, more and more research—these are not rational imperatives at all. The fact that they have become embedded in our present conceptions of truth, value, and human progress gives them no scientific validation: indeed, the biological study of organisms suggests that this one-sided commitment to expansion is, in terms of life, a suicidal process.

Just because science as technology has begun to dominate every other aspect of science, we are bound, if only in self-preservation, to correct the mistakes Bacon unwittingly fostered or sanctioned. Science now makes all things possible, as Bacon believed: but it does not thereby make all things desirable. A good technology, firmly related to human needs, cannot be one that has a maximum productivity as its supreme goal: it must rather, as in an organic system, seek to provide the right quantity of the right quality at the right time and the right place for the right purpose. To this end deliberate regulation and self direction, in order to ensure continued growth and creativity, must govern our plans in the future, as indefinite expansion and multiplication have done during the last few centuries. The center of gravity is not the corporate organization, but the human personality, utilizing knowledge, not for the increase of power and riches, or even for the further increase of knowledge, but using it, like power and riches, for the enhancement of life. On these terms it may be that all the work that has been turned out by Solomon's Houses these last four hundred years will have to be done over again, or at least be revised and amplified and integrated and made humanly more adequate in order to do justice to all the dimensions of life.

The greatest contribution of science, the most desirable of all its many gifts, far surpassing its purely material benefits, has been its transformation of the human consciousness, through its widening illumination of the entire cosmic and historic process, and its transfer to man of the power to participate, with his whole being, in that process. Has the time not come, then—in technology as in every other aspect of the common life—to re-examine our accepted axioms and practical imperatives and to release science itself from the humanly impoverished and underdimensioned mythology of power that Francis Bacon helped to promote?