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The Rise of Science in Relation to Society

Leonard M. Marsak
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THE RISE OF SCIENCE IN RELATION TO SOCIETY

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FOREWORD

History, we are frequently told, is a seamless web. However, by isolating and studying the strands that compose the tapestry of man's past, we are able to discern the pattern, or patterns, of which it is comprised. Such an effort does not preclude a grasp of the warp and woof, and the interplay of the strands; rather, it eventually demands and facilitates such a comprehension. It is with this in mind that the individual volumes of the MAIN THEMES series have been conceived.

The student will discover, for example, that the population changes discussed in one volume relate to the changes in technology traced in another volume; that both changes are affected by, and affect in turn, religious and intellectual developments; and that all of these changes and many more ramify into a complicated historical network through all the volumes. In following through this complex interrelationship of the parts, the student recreates for himself the unity of history.

Each volume achieves its purpose, and its appeal to a general audience, by presenting the best articles by experts in the field of history and allied disciplines. In a number of cases, the articles have been translated into English for the first time. The individual volume editor has linked these contributions into an integrated account of his theme, and supplied a selected bibliography by means of footnotes for the student who wishes to pursue the topic further. The introduction is an original treatment of the problems in the particular field. It provides continuity and background for the articles, points out gaps in the existing literature, offers new interpretations, and suggests further research.

The volumes in this series afford the student of history an unusual opportunity to explore subjects either not treated, or touched upon lightly in a survey text. Some examples are population—the dramatis personae of history; war—the way of waging peace by other means; the rise of technology and science in relation to society; the role of religious and cultural ideas and institutions; the continuous ebb and flow of exploration and colonialism; and the political and economic works contrived by modern man. Holding fast to these Ariadne threads, the student penetrates the fascinating labyrinth of history.

BRUCE MAZLISH
General Editor

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INTRODUCTION

The scientific revolution of the seventeenth century was contemporaneous with the rise of capitalism and Puritanism, with the growth of democracy and of the modern state. Attempts have been made in recent years to establish causal connections among these various phenomena, with inconclusive results. We have not yet succeeded in answering the question, why did science take root in Europe in early modern times, and flourish thereafter? Our task in this volume is to expose some of the problems involved in trying to answer this question and, at the very least, to describe those conditions which were instrumental in the growth of science. Therefore we have selected certain articles and essays that discuss the relation of science to society, industry, government, religion, and the arts, in its development from the fifteenth century to the present.

No effort has been made to be exhaustive in our coverage, but simply to touch on all the important aspects of the social relations of science. For example, the reader will find no mention made of Galileo's trial, but there is sufficient material to illustrate the troublesome relationship of science and politics. Certain early essays like R. K. Merton's on Puritanism and science have been omitted, but their contents have been examined in other more recent articles included here. Insofar as possible we have arranged materials topically as well as chronologically in the hope of tracing the development of science in relation to society, if not in detail, then in sharp outline.

Science is an intellectual activity that is different from man's other imaginative creations. It claims an exact knowledge of reality, as distinguished from metaphysical knowledge, and so it must make contact with nature at some point. The Medieval artists and craftsmen who turned from books to nature for instruction are sometimes credited with being initiators of the scientific revolution. Among those practical workmen, Giorgio de Santillana singles out the architect-engineer, like Fillipo Brunelleschi, as the progenitor of the modern scientist. His work required him to combine practical and theoretical training, and to make use of tools as well as the principles of construction, thus forging the link between science and technology that has persisted to this day. In addition Santillana argues that what the Renaissance architect tried to express in his work caused him to turn from the dominant Aristotelian philosophy to Platonism. Neo-Platonism, with its emphasis on abstraction and number, was beneficial to the new science; but without a heavy admixture of practical information and goals, Platonism served chiefly mystical ends.

Other scholars, and especially the Marxians, argue even more strongly for the social roots of science, tracing them not to the newly elevated architect, but to the ordinary artisan-craftsman. In an expanding economy the bourgeois came to value the artisan for what he could offer to the solution of practical problems in mining and navigation; to the bourgeoisie, practicality was sometimes more important than rank. Thus it is argued that the economic motives of the business class stimulated scientific discovery. Science, the bourgeois believed, was craft writ large, and what he hoped from it was a series of profitable inventions. The scientist, perhaps himself of bourgeois origin, and the craftsman turned scientist, responded to the new utilitarian motive, now so familiar to us. In this way, it is claimed, head and hand were linked for the benefit of science.

This is the point of view to which A. R. Hall takes exception. While acknowledging that science had much to learn from the crafts, he prefers to lay emphasis on the purely intellectual characteristics of the scientists. After all, the capacity to generalize is what distinguishes the sophisticated investigator from the primitive empiricist or the tinkerer. Few first-rate scientists have been without some background in philosophy; and in the seventeenth century philosophy was learned in schools which were the preserve of gentlemen and perhaps the affluent bourgeois. The bourgeois might turn to science, but when he did so he functioned in the capacity of a scholar, and not a profit-seeking businessman.

There is another way in which commerce might have influenced the scientific revolution. The bourgeoisie came to project not only the profit motive, but their ethic as well. Their ethic, which emphasized power and productivity, hard work and social usefulness, was inevitably reflected in other activities. Indeed, the Royal Society, taking its cue from Francis Bacon, looked to science to win dominion over nature for the relief of man's estate. The Baconian, M. E. Prior points out, saw in the successful scientist certain virtues—diligence, humility before nature, compassion for all men—which were an expression of the new secular spirit.

The sanctions for these virtues were perhaps naturalistic and humanistic, but what was their source? R. K. Merton insists that it is found in Puritanism. With his belief in predestination, the Puritan felt a need to prove himself in this world. Thus he valued hard work and abstinence for the greater glory of God, and His kingdom here on earth. This spirit obviously served well in the business world, but it was also useful to the scientist whose job it was to read God's second book of revelation, the book of nature. Merton concludes that primitivist religion directly assisted the growth of science in the seventeenth century.

Recent research challenges the Merton thesis. A. C. Crombie and other scholars look to the Catholic Middle Ages for values relating to science. For example, the monastic orders ran according to a rigid time schedule, and might have supplied the Medieval man with an example of exactitude that was necessary to the sciences of measurement. Moreover, science flourished in France after the revocation of the Edict of Nantes with almost as much success as it did in England. On another front, T. K. Rabb demonstrates that the Puritan values were essentially religious, as one might expect, and not entirely conducive to science. He suggests that it was as Baconians and revolutionaries that some Puritans supported science during the interregnum, seizing upon the Baconian ethic in their effort to establish a new order of things in government. As a consequence science was in disfavor after the Restoration, and it was not till long afterwards that the spirit of practicality found an avenue for expression when it was enshrined in the Protestant dissenting academies as the goal of education. By the mid-eighteenth century these political struggles were over in England, and Englishmen were content simply to exploit science in the interest of industry and government.

France, however, learned the practical value of science even earlier. It is uncertain what Louis XIV had in mind when he chartered the Académie des Sciences in 1666, but there is no doubt that his government sought to exploit the spirit of scientific rationalism that marked its investigations. Louis' military engineer conducted his campaigns with scientific precision, and France was treated at first to a succession of victories won with unfailing exactitude. The Enlightenment philosophers objected to such practical interests for the sake both of science and society, whose progress they viewed as being mutually dependent. Science and society alike, they thought, would benefit by peace, but even more by the untrammeled freedom to investigate. Having an interest in the reform of French society, they welcomed the spread of scientific inventions that would be beneficial to man, but they especially valued the scientific methodolgy, for with this device they could examine society and, understanding it, change it. *Philosophes* like Fontenelle saw in the method of science a way of mind that took nothing on authority, but appealing solely to reason and experience, arrived at truth which might one day free man from the ignorance, error, and superstition that have filled his history and saddled him with bad government. Thus for the Puritan and *philosophe* alike science was a hopeful creed that had revolutionary implications.

It was for this reason that Napoleon mistrusted the scientist. The skeptical quality of science displeased the military dictator who thought that scientists were useful people when they attended to the needs of the state, but who were likely to be dangerous to order and authority if their need for freedom should be taught to others. Most artists and writers, he thought, could be counted on to be more diverting, while being less critical, than the scientists. We might reverse that judgment today, but Napoleon's reaction to the intellectual was not a new one. In his book, *The Crime of Galileo,* Santillana demonstrates that Galileo's fight with the Church was not an example of the warfare of science with theology, but a political contest in which Galileo was by no means the innocent victim. Galileo asked the Church to embrace the new science as the best way of responding to the Protestant challenge, while his opponents believed in holding the line against all innovation. The result of the battle was a defeat for science and support for the arts in an effort to win converts through a direct appeal to the senses. (Louis XIV also knew the value of the arts for ornament and propaganda purposes, and he supported them far more lavishly than he did the sciences.) Napoleon was simply the latest, not the last, authoritarian to be suspicious of science for its liberalizing tendencies.

However, by the time Darwinism was accepted such had become the prestige of science that all sides appealed to it for justification—pacifists and exponents of war; racists and anti-racists; spokesmen for capitalism like Herbert Spencer; and socialist theorists, liberals, and authoritarians. Many thinkers in the nineteenth century claimed absolute knowledge for science, which they fashioned into a new orthodoxy. They enshrined science in disobedience to its precepts that nothing be accepted on authority and that it remain forever open-ended. From this use of science it was an easy step to abusing it in one's own interest. The Nazis talked of Aryan and non-Aryan science and committed murder with great efficiency in a grotesque parody of science, which they perverted to an activist and irrationalist faith. In the Soviet Union science is required to serve an ideology that logically predetermines ideas, thereby converting science into a new scholasticism. When the Russians have wanted practical results from science they have been forced to allow it the freedom it requires. What Bernard Barber details as the liberal values of science—rationality, utilitarianism, universalism, individualism, and meliorism—are in reality best suited to democracy. Only in a liberal society, Barber says, can we expect the preservation of those values on which science itself depends.

But even in the liberal societies we are beset today by the problem of science. Derek Price defines it in terms of the unprecedented growth and bureaucratization of science, to the loss of other pursuits and to the detriment of science itself. C. P. Snow has given the problem its popular exposition in his famous *Two Cultures and the Scientific Revolution*. Unfortunately his book has served in large measure to confuse the issue. Describing the present conflict between science and the arts, Sir Charles considers the victory of science a foregone conclusion. Prudently, he laments the failure of communication between artist and scientist, the more so that each could benefit from the other. However, to talk as he does of two distinct and alien cultures—the scientific looking to the future, the humanistic to the past—is to misstate the problem. We need to remember that science and the humanities have been parts of one culture in our history and that the achievements of each have been reflected in those of the other. If there are two cultures today, then they may be listed as the earlier humanist-scientific one, possessed of the values that Barber describes, and the more recent pragmatic one whose measure of truth is practical results. As the following essays make abundantly clear, science and the humanities share the same values. The quest for knowledge, be it that of the physicist or the poet, implies a commitment to truth rather than falsehood and a responsibility that cannot be escaped. There are some humanists who fail to recognize this elementary fact of ethics, just as there are scientists who fail to do so in their lives and work. Sir Charles perceives this only in part.

In reality what worries C. P. Snow is that our political leaders, who have had their education in the older disciplines, must make fateful decisions without understanding the new science that has shaped our environment. Nevertheless, the decisions they make remain primarily political and not scientific. Of course it is important for our leaders to have some scientific information, but it is more important for them to be men of good will and intelligence who have some understanding of science's place in society and its social uses. To act wisely in matters of science we must know that science is more than a technique and a set of practical results; it is an integral part of our culture which expresses our best aspirations—rationality and altruism. That these values are intrinsic to science and contribute to its moral meaning was clear to Francis Bacon and to his followers in the humanist tradition of the Renaissance. It is hoped that the following essays will not only describe the vicissitudes of science since the early modern period, but also help to clarify its role and assess its value in Western civilization.

THE ROLE OF ART IN THE SCIENTIFIC RENAISSANCE *

Giorgio de Santillana

Giorgio de Santillana is Professor of the History of Science at the Massachusetts Institute of Technology. In the following article, which repays close study, he traces the relation of science to art, society, and philosophy during the Renaissance, and suggests that the artist's techniques and vision gave a new direction to science in the fifteenth century.

. . . Erwin Panofsky has analyzed with great learning and insight the contribution of art to science in many fields. He has rightly insisted that above all the discovery of perspective, and the related methods of

* Reprinted with permission of the copyright owners, The Regents of the University of Wisconsin, from Marshall Clagett, editor, *Critical Problems in the History of Science*, The University of Wisconsin Press, 1959. See Erwin Panofsky, *Studies in Iconology*, N. Y., 1939; and *Galileo as a Critic of the Arts*, The Hague, 1954; Giorgio de Santillana, *The Age of Adventure*, Boston, 1957. [Editor's note.]

drawing three-dimensional objects to scale, were as necessary for the development of the "descriptive" sciences in a pre-Galilean period as were the telescope and the microscope in the next centuries, and as is photography today. This was particularly the case, in the Renaissance, with anatomy. In this field, it was really the painters, beginning with Pollaiuolo, and not the doctors, who practiced the thing in person and for purposes of exploration rather than demonstration. In all this I cannot but accept Panofsky's verdict: Art, from a certain point on, provides the means of transmitting observations which no amount of learned words could achieve in many fields. For myself, I am reminded of a letter of Ludovico Cigoli, the painter, apropos of Father Clavius and his bizarre ideas of the surface of the Moon being made of something like mother-of-pearl: "This proves to me again," he writes, "that a mathematician however great who does not understand drawing is not only half a mathematician, but indeed a man deprived of sight." In such words there lives intact the spirit of Leonardo, although they were written a century later. And so there we are back at Leonardo. But I would rather avoid, at this point, being drawn into the Vincian jungle, where the historian of art meets the historian of science, at best, as Stanley met Dr. Livingston—to get him out.

What I intend to do, in this essay, is to concentrate on the early period, which centers around Filippo Brunelleschi (1377–1446). Its importance, I think, has not been sufficiently brought to light. We are here at the initial point where the historian has to unscramble ideas. Brunelleschi around 1400 should be considered the most creative scientist as well as the most creative artist of his time, since there was nothing much else then that could go by the name of creative science.

We must not superimpose our own image of science as a criterion for the past. It is Brunelleschi who seems to define the way of science for his generation. Who was it that gave him his initial scientific ideas? Was it Manetti or, as others suggest, Toscanelli? Or someone else, still? Under what form? A historian of art, Pierre Francastel, has some veiled reproaches against historians of science. "So little is known," he says, "about history of science in that period, that we have no bearings."

. . . .

. . . We have not yet created our own techniques of analysis in that no man's land between art and science; we have all too few of the facts and none of the critical tools, if we except some penetrating remarks by philosophers like Brunschvicg, who indicated in this period a moving from "Mechanicism" to "Mathematicism." And even so, what do such words really mean, and in what context?

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Two great issues come to mind when we think of that epoch-making change. One is the rise of the modern concept of natural law over and against the medieval one which applies to society, another the intellectual "change of axes" which allowed an explanation of nature no longer in terms of form but in terms of mathematical function.

On these issues, history of science has not much to say before the time of Galileo and Descartes, except to point up the well-known scholastic attempts. Prophetic utterances are quoted, which, scattered over three centuries, fall short of conclusiveness. We are still looking for where the thing actually *took place* in its first form.

Let us then try to make a landfall at a point where art and science, undeniably, join. Brunelleschi created his theory of perspective by experimental means. He built the earliest optical instrument after the eyeglasses. We have Manetti's description of the device, a wooden tablet of about half an ell, in which he had painted "with such diligence and excellence and care of color, that it seemed the work of a miniaturist," the square of the Cathedral in Florence, seen from a point three feet inside the main door of the cathedral. What there was of open sky within the painting he had filled in with a plate of burnished silver, "so that the air and sky should be reflected in it as they are, and so the clouds, which are seen moving on that silver as they are borne by the winds." In the front, at the point where the perpendicular of vision met the portrayed scene, he had bored a hole not much bigger than the pupil of the eye, which funnelled out to the other side. Opposite the tablet, at arm's length, he had mounted a mirror. If you looked then, through the hole from the back of the tablet at its reflection in the mounted mirror, you saw the painting exactly from its perspective point, "so that you thought you saw the proper truth and not an image."

The next step, as we see it now, is to invert the device and let in the light through the pinhole, to portray by itself the exterior scene on an oiled paper screen. This is the *camera obscura,* not quite the one that Alberti described for the first time in 1430, but its next of kin, and it took time to be properly understood. But the whole train of ideas originated with Brunelleschi, between 1390 and 1420.

We have thus not *one* device, but a set of experimental devices of enormous import, comparable in importance to that next device which came two centuries later, namely, Galileo's telescope. Galileo, it will be remembered, announced his instrument as derived "from the more recondite laws of perspective," and in their very inappositeness (at least in modern usage), the words are revealing. The new thing could be understood by opinion only as one more "perspective instrument" and indeed its earliest Latin name was *perspicillum,* whence the English "perspective glass," a name which might apply just as well to Brunelleschi's devices.

We may note that Copernicus himself, untroubled by any modern thought of dynamics, had candidly proposed his system as a proper perspective construction: "Where should the Lamp of the Universe be rightly placed except in the center?" Conversely, there is a "Copernican" spirit about perspective. People will be portrayed as small as they have to be, if they are that distant. There is nothing wrong in looking small if the mind knows the law of proportion; whereas the medieval artists had felt that change of size had to be held within the limits of the symbolic relationship and importance of the figures to the whole.

What the devices of Brunelleschi have done is in every way as significant as the achievement of the telescope. If the telescope established the Copernican system as a physical reality, and gave men an idea of true astronomical space, Brunelleschi's devices went a long way towards establishing in natural philosophy a new idea concerning the nature of light. On these effects of the *camera obscura* I need not dwell, as they have become by now a fairly well-established item in the history of science. By showing the passive character of vision, it cut the ground from under a vast set of theories, primitive and also Platonic in origin, which assume vision to be an "active function," a reaching out, as it were, of the soul. After the discovery of the formation of an image on a screen, the theorizing may well go on for some time, since it is an acquired cultural capital, but the best minds cannot participate in it wholeheartedly, and therefore it is sentenced to eventual decay and fall.

This, then, is . . . all set to be worked out properly. To see the change in the period which concerns us here, we need only compare the consistency and fertility of the new outlook with the optical theories of Ghiberti, Brunelleschi's older friend and contemporary. They are really confused and uncertain footnotes to Alhazen. He sees dimly the new thing that Brunelleschi has established, but he cannot grasp it, he flounders between old and new. Here, too, he is . . . the last medieval. Fifty years later, with Piero della Francesca and Leonardo, we are almost wholly within the new ideas concerning light. It may take until Benedetto Castelli in 1620 to give them uncontested scientific citizenship, but that is because in philosophical theory the old is so much slower to die, the present a coexistence of many epochs. . . .

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Let us be properly historical for a moment. Let us not forget that the Middle Ages had given music a place in the Quadrivium, among the Liberal Arts, but none to painting. If we follow the scheme down into the seven Mechanical Arts which are supposed to be as it were a pallid reflection of the higher ones, we find *lanificium, armatura* (i.e., building), *navigatio, agricultura, venatio, theatrica.* Woolcarding and hunting are recognized arts, while painting and sculpture are not. The figurative arts are left to a purely servile status. They are not supposed to be a freeman's activity. This is not just forgetfulness. Habanus Maurus had taught long since, at the onset of the Middle Ages, the primacy of the Word. Dante himself, who admires Giotto, shows by his idealized use of sculptures in Purgatory that he considers them a kind of teaching aid, heightened maybe by divine touch into some kind of 3-D cineramic animation effect, but still subsidiary and illustrative, whereas poetry, we know, is for him a true philosophical medium, a transfiguration of the object to cosmic significance. And even Cennini, who wrote in 1390, in time for young Brunelleschi to read him, who insists on giving art a professional status beside poetry, provides for it only the old proportion rules of antique convention, plus the new and important caution that the rules do not apply concerning woman, who has no symmetry of proportions, being irrational and a pure thing of nature.

This is the intellectual state of the question at the bursting of the early Renaissance, and it derives little clarification from the first helpless and arbitrary theorizings, or even from Vitruvius whom Brunelleschi, it seems, never troubled to study. As for "science," it was held in trust by professors who cared for none of these things. How then, can these men effect a *prise de conscience?* How does the new intellectual constellation arise?

The problem may become clearer if we think of the second stage, so much more familiar to us. Two centuries later, at the time of Galileo, the struggle between the old and the new form of knowledge is out in the open. Galileo is an acknowledged master of acknowledged science, in mathematics and in astronomy, yet he has to contend all his life with the prejudice which denies him philosophical status. He is treated as a technician and denied any capacity to deal with the true causes of things, which are of the domain of cosmology, as taught in the schools. We all remember how much persuasion he had to spend to show that when we have found a "necessary," i.e., a mathematical cause, we have as true a cause as the mind can encompass and that we need not look farther afield. We know that it took the combined efforts of Galileo, Descartes, and Newton to establish the new idea of a natural philosophy.

If now we come back to 1400 instead of 1600, when the medieval frame of ideas was still an overarching and unchallenged presence, when what we call science was still a hole-and-corner affair without a character of its own, if we think of this group of men who had no connection with the universities, little access to books, who hardly even dressed as burghers and went around girt in the leather apron of their trade—then, I say, it is no use vaguely talking about genius; we have to show some concrete possibilities underlying this sudden creation of a new world of theoretical conceptions.

The period I am referring to is fairly well defined. It is the fifteenth century itself; it starts with Brunelleschi's early work; it has reached a conclusion by 1500 with Leonardo and Luca Pacioli.

The first thing was for these men to have some conception of their social role which allowed them to think legitimately. Here we can see that they found an anchoring point in the old theory, reinterpreted. For just as medicine claimed the "physics" of the schools as its patron science (hence the names "physic" and "physician"), those craftsmen had two of the mechanical arts, architecture and *theatrica,* and above those, music and mathematics. By the time of Pollaiuolo, it is commonly understood that architecture is a straight liberal art.

But mark the difference. The painter remained with only a mechanical art, *theatrica,* back of him. He did in fact tie up with it, in a measure of which we would scarcely be aware if G. R. Kernodle had not collected all the evidence of the connection there was, back and forth, between scenographic art with its repertory of props and the settings of the paintings.[1] This went one way as far as town-planning . . . but even when it remained pure decoration, or play scenes, it shifted the accent from the *liber pictus* of devotional art to the productions and the magnificence of court and city pageants. Ghirlandaio, Benozzo Gozzoli, are names that come to mind: But even in the production of Raphael and Titian, the new "spectacular" element is stronger than the devotional occasion. The architect, instead, has something unequivocally solid to handle. He builds reality.

This leads up to the *third* factor, the new type of patronage from a *new ruling* class. It is significant that just about the time when Brunelleschi was called in as a consultant to the Opera del Duomo (the Works Committee for the Cathedral) its last ecclesiastical members were dropped and it became an entirely lay body: Brunelleschi on his side, once he is the executive, shows a new technocratic high-handedness in firing the master builders *en masse* for obstructionism and re-hiring them on his own terms. But he had not risen to the top without a decisive fight with the guild of the Masters of Stone and Wood, who resisted his plans and even managed to get him, an outsider, arrested for nonpayment of dues. He appealed to the Works Committee and had them clapped in jail. This was the end of the medieval power of those he called scornfully the "Grand masters of the trowel," whom the softer Ghiberti had joined believing no one could ever beat them.

Here we have, then, for the first time the Master Engineer of a new type, backed by the prestige of mathematics and of the "recondite secrets of perspective" (Galileo's tongue-in-cheek description of his own achievements is certainly valid here), the man whose capacity is not supposed to depend only on long experience and trade secrets, but on strength of intellect and theoretical boldness, who derides and sidesteps the usual thinking-by-committee, who can speak his mind in the councils of the city and is granted patents for his engineering devices, such as that one of 1421 which describes in the somewhat casual Latinity of those circles a machine "pro trahendo et conducendo super muris Cupolae lapides, macignos et alia opportuna," or the other, of the same year, for a river lighter equipped with cranes. He is, in fact, the first professional engineer as opposed to the old and tradition-bound figure of the "master builder": He is the first man to be consulted by the Signoria as a professional military engineer and to design the fortifications of several towns: His work is the precondition of the first textbook, that of Francesco di Giorgio Martini. But still and withal, he is acknowledged to the end of his life as the great designer and artist; not only that, but as the man who masters the philosophical implications of what he is doing. Donatello may be acquainted with the Latin classics; he is still considered a craftsman. Brunelleschi is not; he stands as an intellectual. It is only a century later that the fateful distinction emerges between pure and applied art. By that time, the pure artist himself is hardly an intellectual.

Finally, we have the fact that this complex of achievements by a well-led group of great talents—Manetti, Ghiberti, Donatello, Massaccio, Uccello, Luca della Robbia, with Brunelleschi as leader—found a literary expounder of comparable talent in the person of Leon Battista Alberti (d. 1472) who gave their ideas full citizenship in the robed world of letters and humanism—something that only Galileo was able later to achieve by himself. It will have been a fragile and fleeting conjunction, no doubt. By insisting on a "science of beauty" Alberti perpetuated the rigidity of medieval disciplines with their ancient idea of "method," and their dictation of what is right. It will end up in mere academism, about the time when science breaks forth with its own idea of method and of truth. But as long as it lasted, in the period of creation, it has been a true conjunction, both in one. Alberti only paraphrases Filippo's words . . . when he says of the new art of architecture: "If it ever was written in the past, we have dug it up, and if it was not, we have drawn it from heaven." That "social breakthrough" that the new science of Galileo effected through the telescope, we find here in its early counterpart or rather first rehearsal. Everyone in 1450 was aware that a boldly speculative theory had preceded the complex of achievements, until the Dome of the Cathedral rose unsupported in its greatness, "ample enough," says Alberti, "to hold in its shade all the peoples of Tuscany."

We have lined up, one, two, three, four, the preconditions, or what our dialectical colleagues would call the objective possibilities for a scientific renascence, as well as, I daresay, the proper revolutionary consciousness; yet, even if we go and comb the patent records in approved dialectical style, we shall not be able to register the birth of modern empirical science. We are left with the question we started out with: "What was it? In the name of what?" . . .

What did those men, then, actually transmit? The feeling of the high dignity of mathematics, for one, as vouched for by Platonic wisdom; the hope in mathematics, as revived in the preceding century by famous scholars like Bacon and Grosseteste; most of all, the beliefs and wondrous intimations to which Christian intellectual mysticism had clung through the centuries, and which expressed themselves in the "metaphysics of light."

With this body of doctrine we are fully acquainted through many expositions. It starts from the Platonic analogy of God with the sun, that is set forth in the myth of the Cave. It pursues the analogy to suggest that, as God is the life of the soul, so the physical world is held together and animated by the force of light and heat, which should turn out to be, as it were, the ultimate constituent of reality. One could not express it better than Galileo does in the Third Letter to Dini in 1615.

> It appears to me that there is in nature a substance most spiritual, tenuous and rapid, which in diffusing through the universe, penetrates all its parts without hindrance, warms, vivifies and makes fertile all living things, of which power the body of the sun seems to be a principal receptacle. . . . This should be reasonably supposed to be somewhat more than the light we actually see, since it goes through all bodies however dense, as warmth does, invisibly, yet it is conjoined to light as its spirit and power, and concentrates in the Sun whence it issues fortified and more splendid, circulating through the universe, as blood does through the body from the heart. This ought to be, if I may risk a supposition, "the spirit that hovered on the face of the waters," the light that was created on the First Day, while the Sun was made only on the Fourth. . . .

Later, Galileo was to insist that he believed the ultimate substrate of reality to be light itself. There is no need, after that, to weigh his explicit professions and reservations with respect to Platonism. The doctrine of light, "a principal access to the philosophic contemplation of nature," as he calls it, is the true Platonic watermark. . . .

. . . . . .

We understand better, after this, certain peculiar characteristics of Alberti's avowed Platonism. Ficino is already starting a trend, and it is natural for Alberti to "move in" on it. But what he brings is very far indeed from Ficino's *Schwärmerei*.

Says Alberti: "Great, small, high, low, light, dark, and all such which are called the accidents of things are such that all knowledge of them is by comparison and proportion. . . ." Does this remind us of something we heard elsewhere? Why surely it does. "In our speculating we either seek to penetrate the true and internal essence of natural substances, or content ourselves with a knowledge of some of their accidents. . . . But I shall discover that in truth I understand no more about the essences of such familiar things as water, earth or fire than about those of the moon and the sun, for that knowledge is withheld from us, and is not to be obtained until we reach that state of blessedness. But if what we want to grasp is the apprehension of some accidents or affections of things, then it seems to me that we need not despair of acquiring this by means springing from measurement and geometry, and respecting distant bodies as well as those close at hand—perchance in some cases even more precisely in the former than in the latter."[2] This is Galileo writing of the sunspots, and the kinship of thought is unmistakable. Galileo is using here diplomatic restraint, for he is arguing against the authorized system. In the *Dialogue,* he will go further and suggest that what is called change of form might be nothing but a rearrangement of invariant parts; later, Robert Boyle will be forthright about it: "This convention of essential accidents [i.e., the order of constituent particles] being taken together for the specific difference that constitutes the body and discriminates it from all other forms, is by one name, because consider'd as a collective thing, called its form."

The word is out, the essential knowledge is not of forms but of the order and position of parts. Although a very religious man, Boyle will not have to retract his words like Nicole d'Autricourt, he will take his chance with the "Epicurean error"; for it has become what we call science.

Alberti has been writing the manifesto of something that he cannot grasp in its full import, for theoreticians know in part, and they prophesy in part; but he—and Leonardo—call it a science, not an art like music, which is a daring commitment, proper science having been properly defined long ago by the authorities in the Trivium and Quadrivium. The new science of light and space is one of "accidents" or properties, something which to the mind of the scholastic could not possibly hang together, or make sense.

Is it that they are unaware of the official stop sign? Surely not. The current language of their time would be enough to point it up unmistakably; that is why they have to work their way around the language. But they do not have to come into conflict with the philosophic doctrine, because they are not compelled, at that point, to choose between "substance" and "accidents."

That grave choice will have to be Galileo's, who is after abstract knowledge. If he decides he cannot know the substance of things, he will have to be explicitly agnostic about it. The artist can be completely confident about the "substance" of his quest, for it is his own artistic creation and nothing else. If it does not exist yet, it is going to exist, of that he is pretty sure, or his life would be bereft of meaning.

Let us restate the thing in Alberti's simple terms. There is a science, perspective, whose aim is correct comparison and proportion, projection in a visual space (we shall see later all that this implies, but Alberti himself need not be aware of it as yet). It allows us, by way of geometric properties, to deal with the object, the substance, architecture itself, or rather *il murare,* as they say so much more concretely, the *act* of raising walls brick by brick. The right walls. If they know what they are doing, that is all they need.

We have come to a point where we can take stock of the situation. We have here a type of knowledge which refers strictly to what "we ourselves are doing," a *conversio veri et facti* which will find its theoretical development with Vico three centuries later. That future development does not concern us here, but its immediate continuity in Leonardo, the student of nature, surely does so. We cannot forget how, after his restless search on all planes for the essential forms and mainsprings of nature, a search which cannot lead to an abstract physics because it presupposes so much more, Leonardo is led at last to set limits to his understanding: "You who speculate on the nature of things, do not expect to know the things that nature according to her own order leads to her own ends, but be glad if so be you know the issue of such things as your mind designs."

This is the end of the trail; the artist has to go back to a knowledge which is not that of nature. Leonardo's attempted system breaks up and dissolves into a magic of form and color that rises to the stratosphere. But no one could deny that the fallout was considerable.

By transforming the concept of substance into something which could be designed and built up through their science of proportion, the mathematical artists have crossed the otherwise unmanageable distance between Substance and Function. Any attempt at bridging it directly by philosophy would have led to an intellectual impasse, worse, to a breakdown. . . .

Shall we try to describe what we called the fallout, as it seeps in invisibly, all around, for generations before the birth of Galileo?

The new science around 1430 is, as we have concluded, operational in character; that is, it defines the object of its quest by what it does about it, with the difference that whereas the modern object is the experimental procedure, its object is *il murare,* the building procedure. It remains rigorously thought out by way of its properties, known and understood geometrically, physically, functionally, aesthetically, and even symbolically. It imports a fullness of knowledge. The perceptual raw material, as it were, of that knowledge is provided by the past of civilization, for it is in the traditional architecture which is already around, on which judgment and criticism have been able to sharpen themselves. That is the stuff which is now going to be transformed. The huge variety and multiplicity of the pre-existent Gothic pile is a wonderful mass of decorative singularities, where the eye is led without break from the minute particular to the immensity of the whole. Ockhamism concluded, as it were. The Gothic structure, thinks Alberti, is a denial of proportion, a seething cosmos of things streaking off towards heaven; we have to bring into it a constructive law which is dictated by ratio and perspective: "A speciebus ad rationes" as Ficino transcribes the Platonic principle.

Let us make this a little clearer. Form, here, for the artist, has the function of *ratio* or cause of all the species, insofar as there are not really many aspects or forms, but *the* form or the Idea ("concetto"), given by draftsmanship. Perspective shows us the actual size of a thing that looks small in the distance; its position in space determines the truth and invariance of the individual object: its projection the true form abiding in it. The module and reality of the particular are shifted from the thing to geometric space. It is in this space of *ratios* that true construction takes place.

I am trying to paraphrase as best I can the actual ideas of a contemporary who thought he saw what was taking place but could perceive only a dim outline. You cannot expect it to be as clear as a theorem. But if this goes as Platonism, it is certainly not the literary variety with its fashionable uplift. We are treated to diagrams and visual pyramids, to a coördinates net on a screen. We are asked to see longitudinal perspective in terms of that other inverted pyramid ending in the flight-point placed on the infinite circle: that mathematical point at infinity in which all the forms and ratios of reality are absorbed or rather "contracted." No one could deny that we are here on Cusan territory, although there could be no question of direct influence, since Nicholas of Cusa was just having his initial ideas in 1433 when Alberti was writing. What these men have in common can only be the source, the unformulated Pythagorean element just then being transformed. Alberti is fully aware that the longitudinal prospective carries the theme of contemplation; it loses itself as Plotinus suggests in that one flight-point. In fact, it is the equivalent of the medieval golden background: But the imagined ensemble of flight points is, with respect to that sensuous gold, utterly abstract—a true intellectual construction, like that of Nicholas of Cusa, ending up on the "circle of infinite radius."

The metaphysical aspect had been fully grasped by Brunelleschi himself, as is shown by his main line of research, the inflexible endeavor pursued through his life to achieve a synthesis between the longitudinal perspective, implying transcendence, and the central perspective, which implied to him an intrinsic organization of space, or, in philosophical terms, immanence. We can follow the successive stages of this study in his great buildings, San Lorenzo, Santo Spirito, the Ospedale degli Innocenti, until the synthesis is achieved right at the time of his death (1446), with the topping of his great Dome. For the Dome is not only his most outstanding solution in static engineering (what was felt as the miracle of unsupported growth), it is also, in its "rib-and-sail" structure as it was called, the conclusive formal solution of a philosophical issue. The slowly convergent triangles are pure geometric forms leading up to infinity, as no hemispherical dome ever could. The Gothic vertical flight has been transposed into another key; it is concluded and held together by the topping Lantern.

At this moment, as if to mark the scientific inspiration of the whole, astronomy comes in with a significant note. Paolo Toscanelli, Brunelleschi's trusted consultant, and no doubt in accord with his friend's wish, had a dial device built into the Lantern as it was being terminated. It was the third novel instrument in the series: a perforated bronze plate, placed so that the sun's beams struck the pavement below along a graded strip cemented into the floor. It turned the Dome, as Lalande was to write in 1765, into the greatest astronomical instrument ever built. The beam was 240 feet long, and it allowed Toscanelli to effect his solstitial measurements of the inclination of the ecliptic reported by Regiomontanus, which gave 23° 30′. It is correct within 1′, which is probably luck, but in any case better for the time than Regiomontanus' own, 23° 28′. It is at present 23° 26′ 40″, owing to the yearly precessional variation.)

Have I been trying, then, to read philosophy or science into art, a thing reproved both by the scientist and by the aesthetician? I trust I have not. We have only to read Alberti to realize these men's keen awareness of their intellectual quest. At a time when what *we* mean by science was still beyond the horizon, when the *name* of science was monopolized by scholastic officials, who officially denied to mathematics any link with physical reality, these men had conceived of an original prototype of science based on mathematics, which was to provide them with a creative knowledge of reality, repeat—creative, and could claim the name of true knowledge in that it dealt with first and last things. There should be some proper way of placing this attempt, in its true dimensions, inside the history of science, but it has yet to be made. . . .

I trust it is plain by now that what is involved in this story are the great categories of scientific philosophy. Erwin Panofsky has characterized the space of classical art as "aggregative." There would have been no better way to describe the space of Aristotle himself, which is nothing but an orderly pile of containers. This commonsensical kind of space is, for a modern, utterly irrelevant. The space of the Renaissance Panofsky describes by contrast as "homogeneous." In our language we might call it a metric continuum. We have seen earlier what it can imply. It is a new potential richness that Leonardo expresses with awestruck phrases.

It is not a matter of realizing its three-dimensionality. It had been three-dimensional for everybody all along, even for the most medieval of artists; we do not hear of their bumping their heads into corners from lack of space perception. It was simply that they had not felt three-dimensionality as relevant to their art. Here it has become a subject for relevance and intense abstract imagination. No one will mind making distant figures as small as they have to be: The space which comprises them in its structure will restore and define their meaning. "Grasp firmly with thy mind the far and the near together. . . ." These are the words of old Parmenides, and they stood for a great beginning already at that time. It is this firm, this creative grasp which makes all the difference.

The closed space of Aristotle is only the tidy arrangement of a simple multiplicity of things, not unlike, let us say, the shipping department of Sears, Roebuck. Whichever way we understand the new space, that of Nicholas of Cusa and Brunelleschi, it is certainly not that. It is for the artist a pure space of diaphanous light articulated throughout by the central design, bringing into action the law of forms from every point of view at once. It is described by Cusanus, in his famous phrase, as "that whose circumference is nowhere and the center everywhere" and the phrase should be enough to show the whole import of the revolution, for Nicholas of Cusa has borrowed it from the description that "Hermes Thrice-Greatest" gives of the soul. Such a transfer to cosmic space of the properties of the soul, with the accent on a "central perspective" of the intellect, is something no medieval would have dared.

Space is for the new imagination a matrix for infinite potential complexities and states and tensions—a matrix awaiting total structure, rather, a manifold of structures. It is on its way to becoming what is for Newton the organ of perception of God, for Malebranche the only intelligible reality, for the theory of central forces the carrier of that incomprehensible property, action at a distance; it is rich enough to bring forth set theory, group transformations, phase spaces, the electromagnetic ether, Riemann's geometry, and the Einsteinian reduction of all reality to properties of the time-space continuum.

To sum up, this investigation seems to suggest that two of the major features of the Scientific Renaissance, namely, the change-over from Form to Function, and the rise of a "natural law" unconnected with the affairs of human society, have their origin in a specific transformation of the arts. They cannot be said to arise out of the scholar's interest in mathematics, which remains wishful, nor out of the development of the crafts per se, nor out of any statistical accumulation of small interactions between the two zones. They are coherently worked out and brought to bear at the time when the representative and building arts form a new idea of themselves, and go through a theoretical elaboration of that new idea, in such a way as to be able to bring it to grips with reality in their creation. This seems to be the moment when the actual shaping of a new operative thought takes place, and it provides some fundamental categories for nascent scientific thought.

I have barely sketched out the outline of the problem. The analytical tools have yet to be forged. The scientist and the historian of art have hardly ever met, and even then under a cloud of misunderstanding. I am only trying to enter a plea for collaboration in a subject which is still tricky and most difficult.

NOTES

1 G. R. Kernodle, *From Art to Theatre, Form and Convention in the Renaissance* (Chicago, 1944).

2 *Discoveries and Opinions of Galileo*, tr. Stillman Drake (New York, 1957).

THE SCHOLAR AND THE CRAFTSMAN IN THE SCIENTIFIC REVOLUTION *

Rupert Hall

Some historians have argued that early scientists learned the experimental method from the superior craftsmen who were beginning to achieve a position of importance in a nascent capitalist society. In rebuttal, Professor Hall cautions against making any false distinction in science between theory and practice. He states that science has probably owed more to the scholar than to the craftsman, but that in so judging he would be careful to distinguish between the various sciences to ascertain which were the more theoretical and which the more practical in their methodologies.

Never has there been such a time as that during the later sixteenth and the seventeenth centuries for the great diversity of men in the forefront of scientific achievement.[1] A proportion of those who contributed to the swelling literature of science were in a broad sense professionals: indeed, a sizable proportion, since many minor figures enlarge this group. Among these professionals were university teachers, professors of mathematics, anatomy, and medicine; teachers of these subjects, especially applied mathematics, outside the universities; and their various practitioners—physicians, surveyors, mariners, engineers and so on; and lastly the instrument-makers, opticians, apothecaries, surgeons, and other tradesmen, though their great period in science is to be found rather in the eighteenth century than in the seventeenth. These men,

* Reprinted with permission of the copyright owners, the Regents of the University of Wisconsin, from Marshall Clagett, editor, *Critical Problems in the History of Science,* The University of Wisconsin Press, 1959. See: J. D. Bernal, *The Social Function of Science,* London, 1939; G. N. Clark, *Science and Social Welfare in the Age of Newton,* Oxford, 1941; Marie Boas, *The Scientific Renaissance,* New York, 1962; B. Hessen, "The Social and Economic Roots of Newton's Principia," in *Science at the Crossroads,* London, 1931; F. R. Johnson, *Astronomical Thought in Renaissance England,* Baltimore, 1937; and E. Zilsel, "The Origins of Gilbert's Scientific Method," *Journal of the History of Ideas,* Volume II, 1941. [Editor's note.]

widely divergent as they were in social origins and intellectual attainments, at least occupied positions in a recognizable scientific hierarchy. Some had won them through academic study, others through private education and research, others again by apprenticeship and pursuit of an occupation closely related to scientific inquiry. All were trained men in some way, whether in mathematics, physic and dissection, or the exercise of a manual craft. Now it is surprising enough, whether we make comparison with the scientific world of recent times, or with that of the later Middle Ages, to find such disparity in the professional group, that is, to find that the definition of scientific professionalism must be so loosely drawn; yet it is still more astonishing that many minor figures in the history of seventeenth-century science, and not a few notable ones, constitute an even more heterogeneous collection. Among these true "amateurs" of science (the distinction has really little meaning), some, it is true, had been exposed to scientific influences of a kind in college or university; yet the creation of a permanent interest thus, in an ordinary passing student, must have been as rare then as the acquisition of a taste for Latin verse is now. A few also, no doubt, were quietly encouraged by discerning fathers or by private patrons. The rest remains as "sports"; diffusionist and environmental principles hardly suffice to explain their appearance on the scene. One thinks of such men as William Petty, son of a clothier, Otto von Guericke, Mayor of Magdeburg, John Flamsteed, an independent gentleman of modest means, or, most extraordinary of all, Anton van Leeuwenhoek, an unschooled borough official.

Thus one can never predict the social circumstances or personal history of a seventeenth-century scientist. Given the taste, the ability, and freedom from the immediate necessities of the struggle for subsistence, any man who could read and write might become such. Latin was no longer essential, nor mathematics, nor wide knowledge of books, nor a professional chair. Publication in journals, even membership in scientific societies, was open to all; no man's work needed the stamp of academic approval. This was the free age between the medieval M.A. and the modern Ph.D. In the virtual absence of systematic scientific training, when far more was learned from books than from lectures, the wholly self-educated man was hardly at a disadvantage as compared with his more fortunate colleague who had attended the seats of learning, except perhaps in such special fields as theoretical astronomy or human anatomy. There were no important barriers blocking entry into the newer areas of exploration, such as chemistry, microscopy, qualitative astronomy, where all types of ability, manual and intellectual, were almost equally required. Obviously it was statistically more probable that a scientist would spring from the gentry class (if I may use this disputed term) than any other, and that he would be a university man rather than not. But the considerations determining the probability were sociological rather than scientific; if the texture of science was almost infinitely receptive of first-rate ability of any kind, the texture of society was such that it was more likely to emerge from some quarters than from others.

It is needful to traverse this familiar ground in order to set in perspective the dichotomy to which I shall turn—that of craftsman and scholar. It is a quadruple dichotomy—social, intellectual, teleological, and educational. It marks off, broadly, men of one class in society from another—those who earn their bread from scientific trades of one kind or another from those who do not. It distinguishes likewise those achivements in science which are in the main practical or operational from those which are cerebral or conceptual. Thirdly, it draws attention to the different objects of those who seek mainly practical success through science, and those who seek mainly understanding. And finally, if we consider only on the one hand the "scholars" who have been introduced to science by university or similar studies, and on the other the "craftsmen" who have learnt something of practical science in a trade. But we must be cautious in detecting polar opposites where there is in reality a spectrum. The scientific movement of the seventeenth century was infinitely varied, its successes demanded an infinite range of different qualities, and it is against this background of wide inclusion that we must set any attempt at analysis in particular terms.

By far the most closely knit, homogeneous, and intellectually influential of the groups I have described was that of the university men, including both those who remained as teachers and those who departed to other walks of life. Some of the harshest critics of the contemporary "schools," like Bacon, Descartes, or Webster, were nevertheless their products. The opponents of the Aristotelian "forms and qualities" had been firmly grounded in that doctrine; many future scientists found stimulus in the universally required mathematical studies. To exemplify this point, one may consider the earliest membership of the Royal Society in 1663. Of the 115 names listed, I find that 65 had definitely attended a university, while only 16 were certainly non-academic. The remaining 34 are doubtful, but at any rate the university men had the majority. It is still more telling to single out the names which have a definite association-value on inspection; I rate 38 on this test, of whom 32 are "U" and only 6 "non-U." Whether or not we term such men "scholars" is largely a rather unimportant question of definition: at any rate they had in common a knowledge of Latin, some training in mathematics, and an introduction at least to logic and natural philosophy; quite a proportion would also have had such experience of the biological and medical sciences as was available at the time.

It appears then that the medieval association of scientific activity with the universities was weakened, but not disrupted, in the seventeenth century, though the association certainly became less strong as the century advanced. It was weakened not only by the importance in science of men who were not academically trained at all, but by the shift in the locus of scientific activity from the universities, where it had remained securely fixed throughout the Middle Ages,[2] to new institutions like Gresham College, to the scientific societies meeting in capital cities, and to the circles basking in the patronage of a Montmor or a Medici.[3] If a majority of creative scientists had been at the university, they were so no longer in their mature age. Moreover, while in the medieval university there had been little disparity between the instruction given to the student, and the advanced researches of the master, this was no longer the case in the seventeenth century. In the schools of the fourteenth century the master who remained to teach pushed forward his knowledge, in the main, within the framework of ideas, and through study of authorities, with which he had become familiar at a more elementary level. The seventeenth-century university, on the other hand, almost ignored observational and experimental science. The unprecedented advances in scientific technique occurring in physics, astronomy, botany and zoology, and chemistry were not made widely available to students: there was a fairly good grounding only in mathematics and human medicine. The potential investigator had to learn the techniques he required from practice, by the aid of books, and through personal contact with an experienced scientist, often only obtainable elsewhere. Perhaps even more serious was the absence from university courses of the leading principles of the scientific revolution and of the ideas of the new natural philosophy. In the last quarter of the seventeenth century Cartesian science was indeed expounded in some of the colleges of France, and less widely elsewhere, but dissemination of the thought of Galileo, of Bacon, and of the exponents of the mechanical philosophy owed little to university courses. Occasional examples of a university teacher having a decided influence upon a circle of pupils—as was the case with John Wilkins at Wadham College, Oxford, and Isaac Barrow at Trinity, Cambridge—hardly vitiate the general conclusion that the activities of various societies, books, and journals were far more potent vehicles of proselytization, which is supported by many personal biographies. However stimulating the exceptional teacher, formal courses were commonly conservative and pedestrian: it is curious to note that the two greatest scientists of the age who were also professors, Galileo and Newton, seem to have been singularly unremarkable in their public instruction. If the universities could produce scholars, they were ill-adapted to turning out scientists; the scientist had to train himself. Many who accomplished this transition regarded it, indeed, as a revulsion from the ordinary conception of scholarship. The learning they genuinely prized, in their own scientific disciplines, they had hardly won for themselves. It would surely be absurd to argue that Newton was less a self-made scientist than Huyghens, or Malpighi than Leeuwenhoek, because the former had attended a university and the latter not.

It lies outside my brief to discuss the fossilization of the universities, which, from what I can learn, the Renaissance did little to diminish so far as science was concerned, nor the rise of the new science as a rejection of academic dogma. Recent investigations would, I believe, tend to make one hesitant in concluding that the innovations and criticisms in the academic sciences—astronomy, physics, anatomy—which we call the scientific revolution, were the product solely, or even chiefly, of forces and changes operating outside the universities. Rather it would seem that, in relation to these subjects, it was a case of internal strife, one party of academic innovators trying to wrest the field from a more numerous one of academic conservatives. Certainly this was the case with Vesalius and his fellow-anatomists, with Copernicus, with Galileo. It was the academic and professional world that was passionately divided on the question of the inviolability of the Galenic, Aristotelian, or Ptolemaic doctrines; these quarrels of learned men had as little to do with capitalism as with the Protestant ethic. Only towards the middle of the seventeenth century were they extended through the wider range of the educated class.

In the long run—that is to say within a century or so in each instance—the innovators won. In the short run they were defeated; academic conservatism prevented the recognition and implementation of the victories of the revolution in each science until long after they were universally applauded by thoughtful men outside. Whereas in the thirteenth century the schools had swung over to the Greeks and Muslims, despite their paganism and their often unorthodox philosophy, whereas in the fourteenth century the development of mechanics, of astronomy theoretical and practical, of anatomical and other medical studies, had been centered upon them, in the later sixteenth and seventeenth centuries teaching failed to adapt itself to the pace with which philosophy and science were moving. In the mid-sixteenth century the universities could still have formed the spear-head of this astonishing intellectual advance; in Galileo's lifetime the opportunity was lost, and despite the invaluable efforts of individual teachers, as institutions the universities figured only in the army of occupation, a fantastic position not reversed until the nineteenth century. The innovators really failed, at the critical period, to capture the universities and bring them over to their side as centers of teaching and research in the new scientific manner. There were, for instance, many schemes in the seventeenth century for organizing scientific research, and for the provision of observatories, museums, laboratories and so on: yet no one, I think, thought of basing such new institutions on a university. That would have seemed, during the last century, a natural course to follow; and it would presumably have seemed equally natural in the Middle Ages.[4]

Hence it happened that the academic type, the scholar, book-learned in Aristotle or Galen, the Simplicius, the professor who could see the holes in the septum of the heart but was blind to the spots on the face of the sun, became the butt of the scientific revolutionaries.

> Oxford and Cambridge are our laughter,
> Their learning is but pedantry,

as the ballad has it. The passage in the *Discourse on Method* may be recalled, in which Descartes reviews critically the content of education and learning as ordinarily understood:

> Of philosophy I will say nothing, except that when I saw that it had been cultivated for many ages by the most distinguished men, and that yet there is not a single matter within its sphere which is not still in dispute, and nothing therefore which is above doubt, I did not presume to anticipate that my success would be greater in it than that of others; and further, when I considered the number of conflicting opinions touching a single matter that may be upheld by learned men, while there can be but one true, I reckoned as well-nigh false all that was only probable.

After observing that the other sciences derived their principles from philosophy, which was itself infirm, so that "neither the honour nor the gain held out by them was sufficient to determine one to their cultivation," Descartes abandoned the study of letters "and resolved no longer to seek any other science than the knowledge of myself, or of the great book of the world." With this one may compare Bacon's "surprise, that among so many illustrious colleges in Europe, all the foundations are engrossed by the professions, none being left for the free cultivation of the arts and sciences." This restriction, he declares, "has not only dwarfed the growth of the sciences, but been prejudicial to states and governments themselves." The candid appraisal of the first chapter of the *Advancement of Learning* could have been applied to many academic institutions more than two centuries after it was penned.

Admittedly the period when Bacon and Descartes formed such adverse opinions was one early in the scientific revolution; but there is little evidence to show that academic reform progressed rapidly thereafter, and it would not be difficult to quote parallel judgments from a later time. It was not the case, of course, that learned conservatives could see no merit in the study of science. This was no science *versus* humanities wrangle, for the conservatives were themselves teachers of science, of Renaissance science in fact. Their science was Aristotelian and formal; it denounced both Copernicanism and the mechanical philosophy, and distrusted the new instruments and experiments. An analogous situation existed in medicine, where the modernists who were experimenting with chemical preparations and new drugs such as a guaiacum and Jesuits' bark, who followed Harvey and attempted the transfusion of blood, were opposed by the entrenched faculties of so-called Galenists, enemies of every innovation. Nevertheless, the effect was much the same: The "new philosophy" and science were forced to take root outside the academic garden where they should have found most fertile soil.

The effect of the development of new scientific ideas and methods in diminishing the role of the universities as creative centers reinforced rather than initiated the decline of their intellectual prestige, which had begun with the Renaissance. Then, too, new movements in learning and scholarship were at least as much associated with the activities of private scholars, as with those of university teachers. Private patrons had been as energetic in encouraging neo-classical modes of writing and sculpture, as they were to be in promoting science in the seventeenth century. Already in the Renaissance academic learning was reproached for its inelegance in the classical tongues, its imported Arabisms, its lingering attachment to imperfect texts, its barren philosophy. No one was more scathing of academic pedantry than Erasmus, not to say Paracelsus. "Then grew the learning of the schoolmen to be utterly despised as barbarous," says Bacon, so that when he himself attacked the fine philosophic web of scholasticism—too many words spun out of too little matter—he was but repeating an old canard. This revulsion of the Renaissance scholar from the "barbarousness" of still-medieval universities was, as is well known, a linguistic and textual one in the main; it did not touch so much the content of thought as its expression, nor did it, in particular, greatly disturb the pre-eminent position of the ancient masters of science. This aspect of the Renaissance can most clearly be seen in the history of medicine during the first half of the sixteenth century. Some of the lost ground the universities recovered; they began to teach Greek and Ciceronian Latin; more attention was paid to history and literature and less to disputative philosophy. But they could not recover their medieval pre-eminence as cultural centers—particularly perhaps in northern Europe—and the scientists of the seventeenth century had only, in a sense, to follow the path which Renaissance humanists had trodden, in rejecting it.

The object of the preceding remarks is to justify my conception of the scientific scholar of the sixteenth and seventeenth centuries, as a man learned not merely in recent scientific activities and methods, but in the thought of the past. It seems superfluous to argue that the majority of the scientists of the time were of this type, neither technicians nor ignorant empiricists. Certainly the learning of Galileo, or Mersenne, or Huyghens, or Newton, was not quite like learning in the medieval or Renaissance conception; they may have been as deficient in the subtleties of Thomist philosophy as in the niceties of Greek syntax; but to deny that they were learned scholars in their field and in their outlook, would be to deny that any scientist is entitled to be called learned.

I have tried also to trace in outline the way in which, at this time, scientific learning diverged from other branches of scholarship, without wholly severing its affiliations with academic institutions. One might also ask the question: how far was the new scientific spirit of the seventeenth century brought into being by activities of a purely scholarly kind—for example, through the evolution of certain principles of logic during the Middle Ages, or through the activities of the persistent students of Greek science in the Renaissance?

The latter especially furnished the core of an interpretation of the scientific revolution which held favor until recent times. To put it crudely, the scientific revolution was seen, according to this view, as the terminal stage of a scientific renaissance beginning about the mid-fifteenth century, and characterized chiefly by its full exploration of classical scientific texts, which was aided particularly by the invention of printing; the scientific renaissance was itself regarded as a classical reaction against the gothic barbarity of the Middle Ages.[5] This interpretation is in effect an extension of Bacon's, to which I referred earlier; an extension which Bacon himself was unable to make because he did not know that the revolution he sought was going on around him. Clearly, if such a view is accepted, it attaches a very great importance indeed to the activity of the scholar-scientists of the Renaissance, who besides polishing and extending the works of the most authoritative ancient authors, shed a full light on others, such as Lucretius, Celsus, and Archimedes, whose writings had not previously been widely studied.

The merits of this hypothesis of the origin of the scientific revolution are as obvious as its defects. It draws attention to the weight of the contribution of sheer scholarship, and of the amazing Hellenophile instinct of the Renaissance, to the change in science which occurred between 1550 and 1700. No one would deny the connection between the mechanical, corpuscular philosophy of the seventeenth century, and *De natura rerum*; nor the significance for anatomy of the intensive study of Galen; nor would he dispute that the virtual rediscovery of Archimedes transformed geometry, and ultimately algebra. Equally, however, it is clear that this is far from being the whole story: the instances I have quoted are not universally typical ones. The history of mechanics before Galileo, which has been so elaborately worked out in the present half-century, proves the point. Medieval science was not abruptly cut short by a classical revival called a renaissance: it had much—how much must be the subject of continuing research—to contribute to the formation of modern science. Very important threads in the scientific revolution are not really traceable to antiquity at all, at least not through the channels of scholarship; here the chemical sciences furnish examples. Above all, the renaissance-scholarship interpretation fails to account for the *change* in science. If anything is fairly certain, it is that the intention of the Renaissance was the imitation of antiquity, and there is evidence that this ideal extended to the scholar-scientists. Yet the pursuit of this ideal seems to have endured least long in science, of all the learned subjects; it had ceased to have force long before the end of the sixteenth century. There never was a true Palladian age in science, and the limitations that had bound the Greeks themselves were relatively soon transcended in Europe. Why this was so is really the whole point at issue, and the Renaissance-scholarship interpretation does not squarely face it.

Nevertheless, if that view is not completely adequate, it must serve as an element in any more complete interpretation. The different view of the importance of scholarly activities, this time in the Middle Ages, that I mentioned previously, has won ground much more recently. It is one that the non-medievalist has some difficulty in evaluating, and it would be inappropriate for him to criticize it. I had better state my conception of its tenets at the risk of oversimplification: that medieval philosophers evolved a theory for the investigation of natural phenomena which was essentially that applied with success in the scientific revolution. It is not claimed for those who elaborated this theory that they were themselves as eminent in experiment, or observation, or the use of mathematics as their successors; its applications—other than to optical phenomena and the discussion of impetus—seem to have been few and sporadic. It was a scholar's method of science, vindicated by some successes, which only awaited general application to transform the whole exploration of nature, and this the method found in the late sixteenth and seventeenth centuries. Again, the great importance is attached to the role of the scholar; the scientific revolution, it might be said, is the direct consequence of a philosophic revolution.

At the same time, it is evident that there is a measure of incompatibility between these two alternative appraisals of the supposed contribution of scholars to the genesis of modern science. One lays emphasis on content, the other on method; if the medieval ideas on method are pre-eminently important, then the Renaissance revival of classical science is irrelevant, and vice versa. One view, if allowed to fill the whole picture, tends to obscure the other. We are not forced to an exclusive choice, however, and I think it may be granted that a compromise which allows room for both views is possible. It would seem to be the case that while one theory best accounts for certain aspects of the development of science in the sixteenth and seventeenth centuries, the other best explains other aspects. Nor should it be forgotten that changes of emphasis within the scope of the classical tradition may be attributable, in part at least, to changed ideas of method derived from the Middle Ages. I mentioned earlier the rediscovery of Lucretius in 1417, and the connection of this with the mechanical philosophy of two and a half centuries later; it may well be that new ideas on the form and structure of a scientific theory had much to do with the preference for the atomistic tradition in Greek thought over the Aristotelian thus evinced. The fuller acquaintance that textual scholarship conferred with those relics of Greek science which best exemplified the newer medieval notions of scientific procedure might have built up a greater pressure for the further application of those notions. For example, if Galileo, unknown to himself, inherited a method of scientific inquiry from medieval philosophers, he thought of himself (on occasion) as practicing a method used with success by Archimedes.

The medievalist view, if I may so term it, raises in a peculiarly acute form the question which seems central to my problem. Is the effective and creative impulse, which urged men to abandon not merely the philosophy and doctrines of medieval science but even their Greek foundations, to be found in the dissatisfaction of learned men with established modes of inquiry, and the theories and practices to which they give rise? In short, was the scientific revolution in the main the product of a sense of intellectual frustration and sterility? If we think this was the case, and that it was the same philosophers, scholars, and intellectuals who suffered this frustration, who found a way of breaking through it to a more rewarding kind of inquiry and a more satisfying mode of scientific explanation, then our historical seeking is at an end. We might of course go on to inquire where this frustration originated and what brought it into being, and we might also ask what factors enabled the learned men of science to break through it, but at least we should have established their crucial role in the actual break-through, and all else would be ancillary.

That such frustration was experienced hardly requires demonstration. It is expressed by Vesalius, when he laments—with whatever element of exaggeration and ingratitude—the wasted effort into which too uncritical a confidence in the exactitude of Galen had led him; by Copernicus, when he speaks of the disagreement of mathematicians, and their ineptitude: "Rem quoque praecipuam, hoc est mundi formam, ac partium eius certam symmetriam non potuerunt invenire, vel ex illis colligere"; and surely conspicuously enough by Galileo. The latter's is the attitude of one who has broken out of the dead circle of ancient thought, and who can, from reliance on his own new knowledge, pity as well as condemn those still bound by the chains of authority:

> Oh, the inexpressible baseness of abject minds! To make themselves slaves willingly; to accept decrees as inviolable; to place themselves under

obligation and to call themselves persuaded and convinced by arguments that are so "powerful" and "clearly conclusive" that they themselves cannot tell the purpose for which they were written, or what conclusion they serve to prove! . . . Now what is this but to make an oracle out of a log of wood, and run to it for answers; to fear it, revere it, and adore it?

Now what the medievalists contend for is, I take it, that such an attitude to authority was already nascent in the Middle Ages, and that it was not merely negative but creative. I quote Dr. Crombie's very plain statement, from the first page of his book on *Grosseteste and Experimental Science* (Oxford, 1953):

> Modern science owes most of its success to the use of these inductive and experimental procedures, constituting what is often called "the experimental method." The thesis of this book is that the modern, systematic understanding of at least the qualitative aspects of this method was created by the philosophers of the West in the thirteenth century. It was they who transformed the Greek geometrical method into the experimental science of the modern world.

Why was it necessary to devise new inductive and experimental procedures at all at this point? Dr. Crombie finds the answer to this question in the problem presented to Western natural philosophers by the scientific texts recently made available to them: "How is it possible to reach with the greatest possible certainty true premisses for demonstrated knowledge of the world of experience, as for example the conclusions of Euclid's theorems and demonstrations?"

This view places the genesis of the scientific revolution at a very high level of intellectual achievement, which is still maintained if we transfer our attention to a somewhat different field from Crombie's, namely the history of theories of mechanics from the Middle Ages down to the time of Galileo. Here again we may note, not merely striking dissatisfaction with the Aristotelian explanation of continued motion founded on the total separation of the moving force from the moved inanimate body, as well as with certain other features of mechanics of supposedly Aristotelian formulation, but definite and partially successful steps towards more satisfactory concepts.[6] When we come to the critical point, with Galileo himself, we contemplate an intellectual struggle of the most sublime kind, which Professor Koyré has analyzed for us. If the ultimate victory here is not the result of prolonged and arduous cerebration, then it is difficult to see what successes could be attributable to thought and reason in science. Just as the medieval criticism of Aristotle had come from scholars, so also it was in the minds of scholars that the battle between old and new in science had to be fought. I should find it difficult to cite an exponent of the "new philosophy" who did not visualize its fate in those terms.

There is a point here, however, that deserves fuller consideration, and allows the craftsman to enter on the scene. For while we recognize science as a scholarly activity, and the reform of science as an act of learned men, it may be plausible to ask whether the impulse to reform was spontaneously generated among the learned. Was it perhaps stimulated elsewhere? Some support for this suspicion might seem to spring from the emphasis that has been laid on empiricism, not merely in the scientific revolution itself, but among its philosophical precursors. Thus, to quote Dr. Crombie again: "The outstanding scientific event of the twelfth and thirteenth centuries was the confrontation of the empiricism long present in the West in the practical arts, with the conception of rational explanation contained in scientific texts recently translated from Greek and Arabic." It is unnecessary to dwell on the well-known interest of at least a few learned men, during the Middle Ages, in such fruits of empirical invention as the magnetic compass, the grinding of lenses, and above all, the important advances in the chemical and metallurgical arts.[7] Similarly, everyone is familiar with the arguments of the Baconian school: that true command—and therefore real if unwitting knowledge—of natural processes had been won by the arts rather than by sciences, and that the scholar would often become more learned if he would consent to apprentice himself to the craftsman. All this might suggest that the increasingly spectacular achievements of empirical technology arrested the attention of scholarly scientists, enforcing some doubt of the rectitude of their own procedures, and still more, leading them to accept as an ideal of the science itself that subjection of the natural environment to human purposes which had formerly seemed to belong only to the arts and crafts.

There are two issues here. One is the fact of technological progress, which some philosophical critics contrasted with the stagnation of science. The other is the reaction of learned men to the state of technology, and this is more properly our concern. Technological progress was not simply a feature of the Middle Ages and Renaissance: it occurred in the ancient empires, in the Greek world, under the Roman dominion, and even in the so-called "Dark Ages." It would be difficult to think of a long period of complete technical stagnation in European history, though individual arts suffered temporary periods of decline. Some craftsmen at some places seem always to have been making their way forward by trial and error. In short, a philosopher of antiquity had as great an opportunity of appreciating the inventiveness of craftsmen as his successors of the sixteenth and seventeenth centuries, and of drawing the same lessons as were drawn then. Indeed, ancient writers were aware of the importance of the crafts in creating the means of civilized existence, and praised works of ingenuity and dexterity; where they differed from the moderns was in their preservation of the distinction between *understanding* and *doing*. They did not conclude that the progressive success of the crafts set up any model of empiricism for philosophy to emulate. They would not have written, as Francis Bacon did, in the opening lines of the *Novum Organum*:

"Man, as the minister and interpreter of nature, does and understands as much as his observations on the order of nature, either with regard to things or the mind, permit him, and neither knows nor is capable of more. The unassisted hand and the understanding left to itself possess but little power. . . . Knowledge and human power are synonymous."

It is the philosopher who has modified his attitude, not the craftsman, and the change is essentially subjective. The success of craft empiricism was nothing new in late medieval and early modern times, and if the philosopher became conscious of its significance for science it was not because such success was more dramatic now than in the past. It was always there to be seen, by those who had eyes to see it, and the change was in the eye of the beholder. It is absurd, for instance, to suppose that the introduction of gunpowder and cannon into warfare was in any serious sense the cause of a revival of interest in dynamics, and especially in the theory of the motion of projectiles, during the sixteenth and early seventeenth century. The ancient torsion artillery provided equally dramatic machines in its day, not to mention the crossbow, mangonel, and trebuchet of the Middle Ages. The simplest methods of hurling projectiles—the human arm, the sling, the bow—pose problems of motion no less emphatically than more complex or powerful devices, and as everyone knows, appeal to practical experience of this primitive kind was the basis for the development of the concept of impetus. The earliest "scientific" writers on explosive artillery, such as Tartaglia, did no more than transfer this concept to the operation of a different device.

Such an example reminds us that it may be naive to assume that even major technological advances suggested, contemporaneously, such questions worthy of scientific inquiry as would, indeed, immediately spring to our minds. The scientific examination of the three useful forms of iron—cast iron, wrought iron, and steel—did not begin until the early eighteenth century; the geometrical theory of gearwheels was initiated about fifty years earlier; the serious study of the chemistry of the ceramics industry was undertaken a little later. I choose deliberately examples of practical science each associated with notable developments in late-medieval craftsmanship: the introduction, respectively, of the effective blast furnace; of the gear-train in the windmill, water-mill, mechanical clock, and other devices; and of fine, brightly pigmented, tin-glazed earthenware. The time-lag in each instance between the establishment of a new craft-skill, and the effective appearance of scientific interest in it, is of the order of 250 years, and in each of these examples it appears *after* the scientific revolution was well under way. If there is some truth in the view that interest in crafts promoted a change in scientific procedures, it is also true that, at a later date, the very success of the new scientific knowledge and methods opened up the possibility of examining craft procedures systematically, which had not existed before.

It would be a *non sequitur* to argue that, because an important measure of technological progress occurred in the Middle Ages (as *we* are aware), medieval scholars recognized the fact and appreciated its significance. Clearly in many instances they did not—that is why the history of medieval technology is so difficult to reconstruct. Our literary records of the Middle Ages were in large part compiled by scholars; the paucity in them of technological documentation—concerning not merely the use of tools like the carpenter's brace and lathe, but major industries such as paper-making and iron-working—is very conspicuous. The historian of medieval technology is notably better served by the artist than by the scribe. This could hardly have happened, had more than a very few scholars been impressed by the empiricism which brought in the windmill, the magnetic compass, the mechanical clock, and so on.

In any case, I hesitate to conclude that the behavior of an empirical scientist—that is, I take it, one who observes and experiments, both to discover new information and to confirm his statements and ideas—is derivable by virtually direct imitation from the trial-and-error, haphazard, and fortuitous progress of crafts. This seems to me to be the defect of the view that sees the new scientist of the seventeenth century as a sort of hybrid between the older natural philosopher and the craftsman. It is easy enough to say that the philosopher thought much and did little, while the craftsman did much but had no ideas, and to see the scientist as one who both thinks and does. But is such a gross simplification really very helpful in describing or explaining a complex historical transition? Neither Copernicus, nor Vesalius, nor Descartes, to name only three, were more craftsmanlike than Ptolemy, Galen, or Aristotle. Surely scientific empiricism is itself a philosophical artifact, or at least the creation of learned men—here I believe Dr. Crombie has a very strong point—and it stands in about the same relation to craftsmanship as the theory of evolution does to the practices of pigeon-fanciers. It is a highly sophisticated way of finding out about the world in which we live; on the other hand, the notion that direct immersion in the lore of tradesmen was the essential baptism preceding scientific discovery was one of the sterile bypaths from which the scientists of the seventeenth century fortunately emerged after a short time. Modern studies combine in revealing that the empirical element in the scientific revolution, taking the word in its crudest, least philosophical and most craftsmanlike sense, has been greatly exaggerated; correspondingly we are learning to attach more and more significance to its conceptual and intellectual aspects.

This is not to deny that the processes of artisans constituted an important part of the natural environment. If, by an internal displacement, the attention of the natural philosopher was more closely directed to this, and less to his own consciousness and limited academic horizon, he could learn much of what the world is like. As the Middle Ages verged on the Renaissance, an increasingly rich technological experience offered ample problems for inquiry, and besides, much knowledge of facts and techniques. This, apart from their direct technological importance, was the significance for science of the great works of craft-description and invention by Cellini, Agricola, Biringuccio, Palissy, Ercker, Ramelli and others that appeared in the sixteenth century, for while their own scientific content was slight, these authors provided materials and methods for the use of others more philosophically equipped than themselves. Science indeed owes much to technology: but we must remember that the debt was itself created by natural philosophers and other men of learning.

There is no straightforward answer to any question about the whole nature of the scientific revolution. Here it may again be useful to recall the deep distinction between the academic sciences (astronomy, anatomy, mechanics, medicine) and the non-academic (experimental physics, chemistry, botany and zoology, metallurgy)—the latter group being so described because it had no regular place in university studies. Comparing paradigm cases from the two groups, say, astronomy and chemistry, we note that the former was already highly organized, with an elaborate theoretical structure, in the Middle Ages; it used relatively sophisticated techniques, both instrumental and mathematical; searching criticism of one of its fundamental axioms, that is, the stability of the Earth, occurred in the fourteenth century (and indeed long before) while dissatisfaction with its existing condition was vocal and definite before the end of the fifteenth. A fundamental change in ideas came early—in 1543—and was followed, not preceded, by great activity in the acquisition of new factual material, which in turn prompted fresh essays in theory. All this was the work of learned men, and there was little possibility of craft-influence; even if the pivotal invention of the telescope were a craft invention, its scientific potentialities were perceived by scholars. Chemistry reveals a very different historical pattern, in which almost everything said of astronomy is negated. There was no organized chemical science before a comparatively late stage in the scientific revolution; there was no coherent theory of chemical change and reaction; there was no clearly definable classical and medieval tradition to challenge; the conception of chemistry as a branch of natural philosophy was late in establishing itself, and involved a lengthy fact-gathering stage that preceded the formulation of general theories; and in all these developments the influence of craft-empiricism was strong. It can hardly be doubted that the range of chemical phenomena known to craftsmen about 1550 was much greater than that known to scholars, and that, as Professor C. S. Smith has pointed out, craftsmen had developed both qualitative and quantitative techniques of vital necessity to the growth of chemistry as an exact science.[8]

Sometimes, when one turns from considering the history of such a science as mechanics or astronomy to that of, say, chemistry or a biological subject, it seems as though the transition is from one discipline to another completely alien to the first. Nor is it enough simply to admit that some sciences developed more slowly than others; the situations are really different, so that Lavoisier's work in chemistry cannot be made strictly analogous, point by point, to that of Newton in celestial mechanics or optics. Hence all generalizations concerning the scientific revolution require qualification when the attempt is made to apply them to a particular science.

Perhaps I may illustrate this in the following way. The contributions of craftsmanship to the development of scientific knowledge in the sixteenth and seventeenth centuries seem to be analyzable under five heads:

(1) the presentation of striking problems worthy of rational and systematic inquiry;
(2) the accumulation of technological information susceptible to scientific study;
(3) the exemplification of techniques and apparatus adaptable from the purposes of manufacture to those of scientific research;
(4) the realization of the scientific need for instruments and apparatus;
(5) the development of topics not embraced in the organization of science proper.

The incidence of these contributions is highly variable among the individual sciences. None are strongly relevant in anatomy, medicine, or indeed any biological science, except that (4) would apply to microscopy. All the sciences demonstrate an increasing dependence on the instrument maker's craft. Again (4) is relevant to astronomy, while mechanics draws very slightly upon (1) and (2). Chemistry, on the other hand, exemplifies all these possible contributions, and most forms of applied science—other than mathematical sciences—owe much to the fifth contribution. All we can conclude, therefore, is an obvious truism: that those sciences in whose development empiricism played the greatest part are those in which elements derived from craftsmanship had the most effect. It does not follow, however, that the empirical sciences are those that best exhibit the profundity or the nature of the change in scientific thought and work, nor that the theoretical function of scholars is insignificant even in these sciences. Rather the converse would seem to be true, namely that some of those scientists, like Robert Boyle, who at first sight seem to be highly empirical in their scientific work and attitude, were in fact deeply engaged in the search for general theories and laws. The academic and above all the mathematical sciences were not only those that advanced fastest, but they were already regarded as the models for the structure of other sciences, when these should have reached a sufficiently mature stage. In an ascending scale of sophistication, it was regarded as desirable to render all physical science of the same pattern as mechanics and astronomy, and to interpret all other phenomena in terms of the basic physical laws. The first great step towards the attainment of such an ambition was Newton's *Principia,* a work soon regarded by many as the ultimate manifestation of man's capacity for scientific knowledge. I believe it would be wrong to suppose that the scientists of the late seventeenth century, with such rich examples before them, were content to remain indefinitely at the level of empiricism or sublimated craftsmanship, though indeed in many branches of enquiry it was not yet possible to soar far above it. They were aware that the more abstruse and theoretical sciences, where the contributions of learned men had been greatest, were of a higher type than this.

Perhaps I may now summarize the position I have sought to delineate and justify in the following six propositions, in which it is assumed as an axiom that a science is distinguished by its coherent structure of theory and explanation from a mass of information about the way the world is, however carefully arranged.

(1) The scientific revolution appears primarily as a revolution in theory and explanation, whether we view it in the most general fashion, considering the methods and philosophy of the new scientists, or whether we consider the critical points of evolution in any single science.

(2) There is a tradition of logical (or, more broadly, philosophical) preoccupation with the problem of understanding natural phenomena of which the later stages, from the thirteenth to the seventeenth century, have at the lowest estimate some bearing on the attitudes to this problem of seventeenth century scientists.

(3) Some of the most splendid successes of the scientific revolution sprang from its novel treatment of questions much discussed by medieval scholars.

(4) These may be distinguished from the "contrary instances" of success (or an approximation to it) in handling types of natural phenomena previously ignored by philosophers, though familiar in technological experience.

(5) While "scholars" showed increasing readiness to make use of the information acquired by craftsmen, and their special techniques for criticizing established ideas and exploring phenomena afresh, it is far less clear that craftsmen were apt or equipped to criticize the theories and procedures of science.

(6) Though the early exploitation of observation and experiment

as methods of scientific inquiry drew heavily on straightforward workshop practice, the initiative for this borrowing seems to be with scholars rather than craftsmen.

I dislike dichotomies: of two propositions, so often neither *a* or *b* by itself can be wholly true. The roles of the scholar and the craftsman in the scientific revolution are complementary ones, and if the former holds the prime place in its story, the plot would lack many rich overtones had the latter also not played his part. The scholar's function was active, to transform science; the craftsman's was passive, to provide some of the raw material with which the transformation was to be effected. If science is not constructed from pure empiricism, neither can it be created by pure thought. I do not believe that the scientific revolution was enforced by a necessity for technological progress, but equally in a more backward technological setting it could not have occurred at all. If the genesis of the scientific revolution is in the mind, with its need and capacity for explanation, as I believe, it is also true that the nascent movement would have proved nugatory, had it not occurred in a world which offered the means and incentive for its success.

NOTES

[1] Robert K. Merton, "Science, Technology and Society in Seventeenth-Century England," *Osiris,* IV (1938), 360–632. This is the major study of the sociology of science in a single country.

[2] The more "practical" departments of science, such as alchemy, metallurgy, and cartography, admittedly had little direct dependence on the universities; but it should be remembered that knowledge of fundamental texts in these as well as other topics was derived from them. The universities played an important role in the development of the mathematical and astronomical techniques required for practical ends.

[3] On the origins of scientific societies: Martha Ornstein, *The Role of Scientific Societies in the Seventeenth Century* (Chicago, 1938); Harcourt Brown, *Scientific Organization in Seventeenth Century France* (Baltimore, 1934).

[4] Universities had their anatomy theatres and libraries (often of medieval foundation) and, later, museums and laboratories; the latter were, however, private creations (as at Bologna and Oxford) and failed to become living and growing features of academic life.

[5] For bibliographical details on the scientific activities of Renaissance scholars, cf. George Sarton, *The Appreciation of Ancient and Medieval Science during the Renaissance (1450–1600)* (Philadelphia, 1955).

6 Besides the extensive studies of the history of medieval mechanics by Pierre Duhem, Anneliese Maier and others, convenient short discussions (with further bibliographical details) are in A. C. Crombie, *Augustine to Galileo* (London, 1952); René Dugas, *Histoire de la méchanique* (Neuchâtel, 1950). On Galileo and impetus, cf, Alexandre Koyré, *Etudes Galiléennes* (Paris, 1939), "Actualités scientifiques et industrielles," 852–54.

7 The extent to which the technological progress of Europe during the Middle Ages was due to transmisssion rather than indigenous invention is immaterial here, since such transmission seems to have occurred at the level of craftsmanship rather than scholarship. Cf. Thomas Francis Carter, *The Invention of Printing in China and its Spread Westward,* ed. L. Carrington Goodrich (New York, 1955); Joseph Needham, *Science and Civilization in China* (Cambridge, Eng., 1954—).

8 *Lazarus Ercker's Treatise on Ores and Assaying,* tr. Anneliese Grünhaldt Sisco and Cyril Stanley Smith (Chicago, 1951), pp. xv–xix. Charles Singer *et al., A History of Technology* (Oxford, 1957), III, 27–68.

BACON'S MAN OF SCIENCE *

Moody E. Prior

That science has its uses was readily apparent to seventeenth-century man, but it remained for Francis Bacon to transform this observation into a system of ethics. Dr. Prior's article describes the ethical values that Bacon attached to science, and raises the interesting problem of the source and sanction for the Baconian ethic.

The dominating motive of Bacon's intellectual life was the complete reformation of learning, and he labored under the conviction that he was, almost singlehandedly, promoting a revolution in knowledge to the end that man might win a new empire over things. In those of his writings which he regarded as the parts of his grandiose plan, he gave frequent expression to his new conception of the proper goals of human knowledge and proposed new methods by which they were to be attained. And clearly implicit in this new approach to learning was an

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alteration in the conception of the learned man. Since the new aim and the method were to make unprecedented demands on the knower, it became necessary for Bacon to conceive a new scientist as well as a new science. This is not immediately apparent because it was to the development of his aims and methods that Bacon gave primary attention in his writings. Incomplete as his system remains, the outlines of his plan are clear and explicit, and portions are developed in detail; but the details of his picture of the new man of science are scattered, and the image has to be pieced together. From the writings of such later men as the early members of the Royal Society, for whom Bacon was a patron saint, the common elements of an image of the new scientist are clearly discernible; but though it was largely from Bacon that they caught the lineaments of the ideal which inspired them, the later portrait appears generalized and simplified when compared to the original. Every detail of the character of Bacon's new scientist is rooted in the goals which he set up and the methods he proposed. All of Bacon's objection to the learning of the past, all his hopes for the future, and all his philosophical aims are reflected in the image which he seems to have clearly visualized of the new scientist who was to be the instrument of the new learning as well as its product.

The intellectual, psychological, and ethical qualities which Bacon demanded of his new scientist form an organic concept, but it is possible to distinguish certain qualities which are associated very closely with the requirements of the method and certain others which are necessarily bound up with the proper aims of learning and the rôle which they impose on the scientist. The immediate purpose of Bacon's methodological principles was nothing less than truth and certainty, and the goal he proposed was nothing less than the profound improvement of man's lot. The spirit and tone of his writings is therefore strongly optimistic. But Bacon did not ground his hopes on any extravagant estimate of man's powers. The hard realism of his mind, so clearly manifested in his comments on worldly affairs, is also revealed in his adoption of a very critical attitude toward the limited capacities by means of which man perceives and comes to a knowledge of his universe. Bacon's method, therefore, is founded on a review not only of the errors and defects in learning but of the deficiencies of the knower. If the past was to be swept aside, the mind wiped clear, and a new way charted, the positive program could begin only after all established illusions about man himself had been anatomized and taken into account.

For rigorous critique of the failings in man which stood in the way of attaining certainty Bacon had not far to seek. The Sceptics of antiquity had systematically analyzed the defects in man's capacity to perceive and judge of reality, and had concluded on the basis of this analysis that nothing can be known. Strengthened by new illustrations and revitalized by literary embellishment, notably in the writings of Montaigne, this ancient school enjoyed a vigorous revival during the sixteenth century. But neither in motives nor conclusions were the ancient Sceptics or the new essentially akin to Bacon. Bacon—like others among the philosophers of the new developments in natural science—found the sceptical critique of man powerfully stimulating; moreover, he recognized it as something to be acknowledged and met before a way to truth could be recommended. Bacon's awareness of the force of the sceptical arguments is everywhere apparent, but it is in the famous discussion of the Idols in *Novum Organum* (I, xxxviii–lxviii) that the influence is most direct. Incorporated into a novel analysis and surrounded by many important original extensions can be discovered all of the sceptical "modes." The sceptical deductions and conclusions are, however, missing. Bacon simultaneously accepted scepticism as a critique and rejected it as a philosophy of knowledge: he represented himself as one who maintained not that nothing can be known, but that nothing can be known except in a certain way.

This way—the new method—was thus to provide correctives for the limitations of the knower. The critique of the Sceptics Bacon acknowledged, but despair in consequence of it he regarded as merely the result of neglecting the aid available: "The doctrine of those who have denied that certainty could be attained at all, has some agreement with my way of proceeding at the first setting out; but they end in being infinitely separated and opposed. For the holders of that doctrine assert simply that nothing can be known; I also assert that not much can be known in nature by the way which is now in use. But then they go on to destroy the authority of the senses and understanding; whereas I proceed to devise and supply helps for the same." [1] Scepticism becomes therefore not a philosophy of knowledge but a principle of method: "that which I meditate and propound is not *Acatalepsia* but *Eucatalepsia*; not the denial of the capacity to understand, but provision for understanding truly."

For the defects of the senses Bacon proposed as correctives the use of instruments and, most important of all, experiments. The correction of the defects of the understanding, however, demanded more subtle forms of control. Scepticism as a method called for calmness of spirit equal to the demands of systematic doubt—of unwillingness to assent or deny prematurely. But this was an attitude very different from the *atarazia* and *epoche* of the ancient Sceptics, which it resembles superficially, just as it had little in common with the ultimate triumph over the passion of the Stoics. And it was necessarily opposed to the dogmatism of the system-builders and to the agitation encouraged by the disputatious methods of the schools. Bacon described it as an attitude that mediated between the extremes of dogmatism and scepticism, "between the presumption of pronouncing on everything and the despair of comprehending anything." [2] And its ultimate destination was truth: "Another error is an impatience of doubt, and haste to assertion without due and mature suspension of judgment . . . if a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties." [3]

This restraint of the intellect—the chronic doubt and suspension of mind which were the necessary temperamental consequences of scepticism used as a method—failed to meet the sceptical argument that certainty was unattainable because life was short and art was long, the depth of nature profound and infinite, and the span of man's life finite and subject to the cycles of time. Bacon understood the discouraging potency of these arguments: "But by far the greatest obstacle to the progress of science and to the undertaking of new tasks and provinces therein, is found in this—that men despair and think things impossible. For wise and serious men are wont in these matters to be altogether distrustful; considering with themselves the obscurity of nature, the shortness of life, the deceitfulness of the senses, the weakness of the judgment, the difficulty of experiment and the like; and so supposing that in the revolution of time and of the ages of the world the sciences have ebbs and flows; that at one season they grow and flourish, at another wither and decay, yet in such sort that when they have reached a certain point and condition they can advance no further." [4] Bacon's answer to this melancholy wisdom of the ages was to substitute for it a radical, progressive attitude toward truth and knowledge. One error in the old sceptical view lay in approaching the problem of knowledge in terms of the limits of a single life and to despair because the goal was so clearly out of reach. Bacon was indifferent to this despair because he placed certainty as the limit toward which a properly organized search for knowledge continuously moved. "I propose," he wrote in the Preface to *Novum Organum*, "to establish progressive stages of certainty." The fullness of knowledge lay in the fullness of time, and time was generative in a progressive way: "let great authors have their due, as time which is the author of authors be not deprived of his due, which is further and further to discover truth." [5] For Bacon, "truth is the daughter of time." [6] Truth will therefore appear impossible only when viewed from the conventional perspective as something to be encompassed by individual men through the exercise of their powers of understanding: "touching impossibility, I take those things are to be held possible which may be done by some persons, though not by everyone; and which may be done by many, though not by any one; and which may be done in succession of ages, though not within the hourglass of one man's life; and which may be done by public designation, though not by private endeavour." [7] Thus while granting a premise that traditionally led to despair, Bacon's progressive view of knowledge encouraged an optimistic outlook in the scientist, not only because that new method promised accelerating results but because fulfilment was continuous. Bacon sometimes seems naïve in his hopes that through collaborative effort on the right principles a complete history of nature might be a finite task whose end could be foreseen, but it is difficult to determine at times whether the source of his enthusiasm lies there or in the possibility of continuous progress: "There is therefore much ground for hoping that there are still laid up in the womb of nature many secrets of excellent use, having no affinity or parallelism with anything that is now known, but lying entirely out of the beat of the imagination, which have not yet been found. They too no doubt will some time or other, in the course and revolution of many ages, come to light of themselves, just as the others did; only by the method which we are now treating can they be speedily and suddenly and simultaneously presented and anticipated." [8]

In this progressive view of the problem of knowledge and certainty there was, moreover, a further consequence for the character of the Baconian scientist more profound than chronic optimism. For him there could never be the gratification of bringing all truth into a single order through the strength of the intellect. This, Bacon insisted, was an illusion of the dogmatist, who, out of arrogant pride in the operation of his intellect, substituted the patterns of his mind mistakenly for the complexities of the universe. Real confidence and hope lay only in the realization that the true goal was distant and that it required not one man but many, not one lifetime but generations of men working with a common purpose. In the optimism which grew out of a progressive and collective view of knowledge and truth the Baconian scientist buried his pride.

This subduing of the pride of intellect has a direct bearing on Bacon's views concerning the proper end of knowledge. The failure of learning, Bacon maintained, had resulted from "the mistaking or misplacing of the last or furthest end of knowledge," [9] and the hope for the future of learning lay in the realization of its proper goal: "It is not possible to run a course aright when the goal itself has not been rightly placed. Now the true and lawful goal of the sciences is none other than this: that human life be endowed with new discoveries and powers." [10] If knowledge was to dedicate itself to "the glory of the Creator and the relief of man's estate," [11] it must be directed toward a deep understanding of the behavior of nature and the application of this knowledge to the systematic development and improvement of the arts. The difference between civilization and barbarism, Bacon maintained—replying at the same time to various old and current theories—"comes not from the soil, not from the climate, not from race, but from the arts." And "the empire of man over things depends wholly on the arts and sciences. For we cannot command nature except by obeying her." [12]

In the light of this aim, many conventional and apparently normal motives to study lose their importance for Bacon and in effect become base or misleading: "For men have entered into a desire of learning and knowledge, sometimes upon a natural curiosity and inquisitive appetite; sometimes to entertain their minds with variety and delight; sometimes for ornament and reputation; and sometimes to enable them to victory of wit and contradiction; and most times for lucre and profession; and seldom sincerely to give a true account of their gift of reason, to the benefit and use of men." [13] Some of these common and traditionally admired motives may be, Bacon conceded, "more worthy than others"; they are nevertheless "all inferior and degenerate." [14] Moreover, their setting aside involves a radical departure from traditional standards for the character and conduct of a learned man. The traditional ideal of contemplation as the perfect activity and final good of rational man is abandoned—and so apparently must be its modern analogue, disinterested curiosity. Bacon's scientist is disinterested only in preferring the common good to private good, and Bacon finds it necessary to reject the Aristotelian and scholastic ideal of the contemplative life: "It [the common good] decides the question touching the preferment of the contemplative or active life and decides it against Aristotle. For all the reasons which he brings for the contemplative respect private good, and the pleasure and dignity of a man's self; in which respects no question the contemplative life has the pre-eminence. . . . But men must know that in this theatre of man's life it is reserved only for God and the Angels to be lookers on." [15] The contemplative ideal, by exalting the "pleasure and dignity of a man's self," perverts the end of learning by depriving it of its power. Only a change in emphasis can restore to learning its true character: "this is that which will indeed dignify and exalt knowledge, if contemplation and action may be more nearly and straitly conjoined and united together than they have been." [16]

The inspiration for true learning was for Bacon not the pleasure of study and the excitement of discovery, but the needs of mankind. Though many assertions made during his divided life by this remarkable man have been looked at with suspicion, it is impossible to question the sincerity of his expressed compassion for the lot of man. In his celebrated letter to Burghley, which contains the first recorded statement of his intellectual ambitions, he concludes: "This, whether it be curiosity, or vain glory, or nature, or (if one take it favourably) *philanthropia,* is so fixed in my mind as it cannot be removed." Bacon may have listed the inferior motives because he did not wish to expose his earnestness and sincerity too clearly before the worldly minister, but later expressions of this theme appear with no concessions. The superior ethical motive became inseparable from the intellectually superior end, as though Bacon had realized that no motive other than "philanthropia" could ever guarantee that science would hold to the proper end of learning and consequently employ correct methods. If learning was to become the mastery of nature for the uses of life, it could be guided only by men who were continually inspired by compassion for the lot of man. At the conclusion of the "Proemium" to the *Magna Instauratio* Bacon thus explains his haste in publishing: "The cause of which haste was not ambition for himself, but solicitude for the work; that in case of his death there might remain some outline and project of that which he had conceived, and some evidence likewise of his honest mind and inclination towards the benefit of the human race. Certain it is that all other ambition whatsoever seemed poor in his eyes compared with the work which he had in hand, seeing that the matter at issue is either nothing, or a thing so great that it may well be content with its own merit, without seeking other recompence." Even in his most worldly practical discourses, Bacon discredited as inferior the actions that stem from self-love ("Of Wisdom for a Man's Self"), and proclaimed "philanthropia" as the noblest of man's capacities ("Of Goodness and Goodness of Nature"). Philanthropia was the seed from which the new science must grow, and so the new man of learning must of necessity be touched by the needs of others. How deeply Bacon's own feelings ran can be seen by the following lines from the Preface to *The Great Instauration:*

> Wherefore, seeing that these things do not depend upon myself, at the outset of the work I most humbly and fervently pray to God the Father, God the Son, and God the Holy Ghost, that remembering the sorrows of mankind and the pilgrimage of this our life wherein we wear out our days few and evil, they will vouchsafe through my hands to endow the human family with new mercies.

Compassion is the invariable mark of Bacon's true scientist. Of the personage who addresses the gathering of learned men in *Redargutio Philosophiarum* he writes: "aspectus . . . admodum placidi et sereni; nisi quod oris compositio erat tanquam miserantis." [17] And in the description of one of the Fathers of Solomon's House in *New Atlantis,* almost the first detail has to do with compassion: "The day being come, he made his entry. He was a man of middle stature and age, comely of person, and had an aspect as if he pitied men." [18]

The identification of scientific truth with use and therefore with charity, with power and therefore with pity, is fundamental to Bacon's conception of true learning. . . .

There is an obvious similarity between Bacon's notions about the deadly sin and cardinal virtue in science and the moral ideals of man in the Christian tradition. But the distinction between the ethical virtues and vices of a scientist is not insisted upon in Bacon because it is essentially religious and Christian. Christianity may be the source, but it is not the sanction. The grounds of Bacon's analysis are naturalistic and humanistic, and he derives them out of the aims of true learning and the demands of good method. It is a question of success and failure in the discovery of useful knowledge. The scientist must cultivate charity and shun pride not in consequence of being a Christian but in consequence of being a scientist. Bacon, it is true, represents his scientist as a religious man. To some extent he does so to defend the new learning against the charge that it leads to atheism. Bacon concedes that "a little natural philosophy inclineth the mind to atheism, but a further proceeding bringeth the mind back to religion." [19] Bacon claims also that learning does a service to religion, since the deep investigation into God's works inspires admiration for His glory, and leads to "meditation of the omnipotency of God." [20] Bacon may have written thus in all sincerity. But these considerations play a relatively minor rôle in his preoccupation with science and his apologetics for the new learning: compare, for instance, the trifling and inconspicuous place which the argument from design occupies in Bacon's thought with its ubiquity and extensive development among the English scientists of the next generation. Bacon separated completely the realms of religion and of natural knowledge in the interest of establishing a science free of superstition and presumably a religion free of sophistry. The basis of religion was for him the knowledge of God's will and law, matters which lay beyond man and hence were knowable only through divine revelation. Bacon urged therefore "that we do not presume by the contemplation of nature to attain to the mysteries of God," [21] that the pursuit of natural knowledge be kept clear of religion, and that men "do not unwisely mingle or confound these learnings together." [22] Religion in scientific matters was recommended largely indirectly as a corrective: against the fear that through science unknown power may be granted without adequate restraints, he advised "that all knowledge is to be limited by religion and is to be referred to use and action," [23] and against the danger of "the debasement of arts and sciences to purposes of wickedness, luxury, and the like," he expressed the pious hope that "the exercise thereof will be governed by sound reason and true religion." [24] But when viewed frrom the center of Bacon's thought, this strain seems like conventional embroidery. In the pursuit of the true end of learning with the proper methods, Bacon's man of science had to possess and exercise qualities which by their nature rendered such admonitions superfluous. As long as he functioned as a good scientist he had of necessity to be incorruptible and a good man. Bacon often leaves the impression that the career of science is something of a religion in its selflessness and sense of dedication, and he at times spoke of the future scientists as though they were a priesthood. And always he speaks of the pursuit of natural knowledge as though it were the noblest of human activities.

When viewed as a whole, Bacon's ideal of the scientist establishes a new ideal of man, different from the ideal of the patriot, the saint, *the gentleman courtier* and prince of the Renaissance, and even the citizen of the perfect state. The good man is one who possesses or is capable of exercising the intellectual and ethical virtues demanded by the aims and methods requisite for the discovery of truth in the study of nature, and the good life is the dedication to the improvement through this means of man's lot on earth.

For this man, Bacon envisioned a new rôle in society and a society vastly improved by his dominant rôle in it. The character with which Bacon endowed him rendered him superior to others, and hence Bacon saw him as occupying a superior position in society. His scientist would be a member of an élite class, though not by virtue of birth, or political status, or the possession of an aloof intellectual supremacy. Bacon found it necessary to combat certain conventional notions of social superiority in order that members of the gentry and aristocracy might not be deterred from devoting themselves to such studies under the mistaken notion that certain activities were base. Science required experiments, and therefore the work of artisans and craftsmen was to be cultivated. Moreover, Bacon was impressed by the fact that in the mechanical arts important inventions and discoveries were followed by progressive improvements, whereas in pure learning impressive achievements seemed to end in themselves. He came to respect the qualities which were associated with the mechanical arts, and made a point of calling attention to his own activities in this direction with pride: "For myself, most excellent king, I may truly say that both this present work, and in those I intend to publish hereafter, I often advisedly and deliberately throw aside the dignity of my name and wit (if any such thing be) in my endeavour to advance human interests; and being one that should properly perhaps be an architect in philosophy and the sciences, I turn common labourer, hodman, anything that is wanted; taking upon myself the burden and execution of many things which must needs be done, and which others through an inborn pride shrink from the decline." [25] These views accord with both the humility and the realism which Bacon required of his scientist, but they do not imply that he required of his scientist the psychology of a glorified menial humbly content with his useful drudgery. Though he despised the arrogance which he associated with older ideals of the learned man, when he came to present the picture of the scientist in *New Atlantis* in an imagined perfect setting, he pictured him surrounded by the pomp and reverence usually associated with kings and prelates. The visit of one of the Fathers of Solomon's House is preceded by awesome heraldings of his arrival, and he comes handsomely accoutered, and impressively carried about "in a rich chariot without wheels litter-wise; with two horses at either end, richly trapped in blue velvet embroidered; and two footmen on each side in the like attire." [26] His impressive train is reported, nevertheless, to lack some of the accompaniments of purely regal processions, out of a desire "to avoid all tumult and trouble." [27] His behavior suggests the high priest: "He held up his bare hand as he went, as blessing the people, but in silence." The mariners in the story recount among the remarkable features of Bensalem the courteous refusal of the local dignitaries to accept the usual marks of obeisance, yet Bacon's narrator reports of their visit to the Father of Solomon's House: "When we came in, as we were taught, we bowed low at our first entrance; and when we were come near his chair, he stood up, holding forth his hand ungloved and in a posture of blessing; and we everyone of us stooped down, and kissed the hem of his tippet." In Bensalem the scientists are a consecrated priesthood, and it seems less correct to say of them that they were religious men than that they constituted a religious cult in themselves: "We have certain hymns and services, which we say daily, of laud and thanks to God for his marvellous works: and forms of prayers, imploring his aid and blessing for the illumination of our labours, and the turning of them into good and holy uses."

The loyalties of such men would not be bound by conventional standards. They could have no compelling class affiliations, since useful information could come from the most humble sources. What is more important, such scientists would not be confined by national boundaries. This point is effectively presented in *New Atlantis.* The citizens of Bensalem are forbidden by royal decree from travel outside their kingdom, but this restraint does not apply to certain fellows of Solomon's House, who are termed Merchants of Light. At regular intervals they are sent out to all parts of the globe to gather information on the advances in the arts and sciences: "But thus you see we maintain a trade, not for gold, silver, or jewels; nor for silks; nor for spices; nor any other commodities of matter; but only for God's first creature, which was *Light;* to have *light* (I say) of the growth of all parts of the world." One must not minimize the importance of this theme because of the utopian setting. Bacon's utopia, at least with reference to Solomon's House, comes much closer to being a picture of what the author believed to be possible—as distinct from what he believed to be ideally desirable—than is the case with most ideal commonwealths. In a more straightforward context he had made his views on this point quite clear: "Further, it will not be amiss to distinguish the three kinds and as it were grades of ambition in mankind. The first is of those who desire to extend their own power in their native country; which kind is vulgar and degenerate. The second is of those who labour to extend the power of their country and its dominion among men. This certainly has more dignity, though not less covetousness. But if a man endeavour to establish and extend the power and dominion of the human race over the universe, his ambition (if ambition it can be called) is without doubt a more wholesome thing and more noble than the other two." The humanitarian impulse of the scientist could not be confined to local loyalties and limits, and true knowledge, by its nature, transcended time and space: ". . . if the invention of the ship was thought so noble, which carrieth riches and commodities from place to place, and consociateth the most remote regions in participation of their fruits, how much more are letters to be magnified, which as ships pass through the vast seas of time, and make ages so distant to participate of the wisdom, illuminations, and inventions, the one of the other?" The scientist was of no country, as a scientist; he was a member of an international freemasonry.

That there were dangers in the extension of man's dominion over nature, Bacon was aware. Had his scientist no responsibility to these? Bacon's answer to this question was usually evasive. Certainly it was possible that the new learning might be put to base uses, but are not all good things perverted by evil and foolish men from their proper ends, and is that sufficient reason for discouraging the good things themselves? It was also true that the new knowledge might "open a fountain, such as it is not easy to discern where the issues thereof will take and fall," and that it would make available vast resources to all men; Bacon consoled himself in the hope that the new knowledge and power would be beneficiently employed by the exercise of right reason and religion. But Bacon knew too well the psychology of power to feel greatly comforted by his own casual reassurances. All men were not scientists. Bacon's failure to confront this important question with his customary resoluteness and realism suggests the real measure of his fear. It was only in the utopian setting of *New Atlantis* that he faced the issue squarely and carried the implications of his fears to their logical conclusion: "And this we do also. We have consultations, which of the inventions and experiences which we have discovered shall be published, and which not: and take all an oath of secrecy, for the concealing of those which we think fit to keep secret: though some of those we do reveal sometimes to the state and some not." This brief passage says in effect that just as in the interest of mankind scientists must constitute themselves an international freemasonry or priesthood, in the same interest they must set themselves above the state. To appreciate how remarkable is the appearance of this idea in Bacon, it is only necessary to recall that in defense of the royal prerogative he had opposed Coke in the theory of common law, and that in the essay "Of Judicature" he had described the judges as lions, but as lions under the throne. Bacon had stated with unmistakable clarity his conviction that science—though not necessarily the scientist—must in his own day be separated from religion. This brief passage from *New Atlantis* indicates that Bacon had more than a premonition of the necessity for separating science from politics in future times when the character of scientific discovery and the vital rôle of the scientist in a technological civilization would place in strong relief the foolish and vicious possibilities in the use of the new knowledge by society and its exploitation by political power.

NOTES

[1] *Novum Organum,* I, xxxvii, in *The Works of Francis Bacon,* edited by Ellis, Spedding, and Heath (Boston, 1860–1864), Vol. VIII. All references to Bacon's writings will be to this edition.

[2] Preface to *Novum Organum,* Works, VIII, 59.

[3] *Advancement of Learning,* Works, VI, 133.

[4] *Novum Organum,* I, xcii. Also *Advancement,* Works, VI, 93 and *Valerius Terminus of the interpretation of nature,* Works, VI, 41, 47.

[5] *Advancement, Works,* VI, 129.

[6] *Novum Organum,* I, lxxxiv. Bacon said of his own contributions to knowledge, "I am wont for my own part to regard this work as a child of time rather than of wit." (*Magna Instauratio, Works,* VIII, 25. See also *Novum Organum,* I, lxxviii.)

[7] *Advancement, Works,* VI, 182. See also *Valerius Terminus, Works,* VI, 47.

[8] This progressive aspect of Bacon's view of knowledge seems particularly to have fascinated the English writers on science of a later generation. Their enthusiasm seems often to arise not so much from the expectation, also voiced by Bacon, that the new science would bring in a speedy harvest, as that it gave promise of infinite progress in the effective exploration of an infinite complexity.

[9] *Advancement, Works,* VI, 134. See also *Valerius Terminus, Works,* VI, 34.

[10] *Novum Organum,* I, lxxxi.

[11] *Advancement, Works,* VI, 134.

[12] *Novum Organum,* I, cxxix. This idea is aphoristically stated in the special vocabulary of Bacon's philosophy of nature in *Novum Organum,* II, i.

[13] *Advancement, Works,* VI, 134.

[14] *Valerius Terminus, Works,* VI, 34.

[15] *De Augmentis Scientiarum* (Bk. VII, ch. I), Works, IX, 197–98. See also *Novum Organum,* I, cxxiv.

[16] *Advancement, Works,* VI, 143–35.

[17] *Redargutio Philosophiarum,* Works, VII, 59.

[18] "He detested self-revelations, but whenever he painted the portrait of his ideal philosopher, pity for mankind is the dominant trait." (Benjamin Farrington, *Francis Bacon, Philosopher of Industrial Science* [New York, 1949], 70.)

[19] *Valerius Terminus, Works,* VI, 33. See also *ibid.,* 30 and *Advancement, Works,* VI, 96–97.

[20] *Advancement, Works,* VI, 144.

[21] *Ibid.,* 95.

[22] *Ibid.,* 97.

[23] *Valerius Terminus, Works,* VI, 28. See also *Advancement, Works,* VI, 94.

[24] *Novum Organum,* I, cxxix.

[25] *De Augmentis, Works,* IX, 193.

[26] *New Atlantis, Works,* V, 395–96.

[27] *Ibid.,* 396.

PURITANISM AND THE RISE OF EXPERIMENTAL SCIENCE IN ENGLAND *

T. K. Rabb

In the following selection, Professor Theodore K. Rabb argues with those sociologists and historians of science who believe that Puritanism was a motive force for science. Rabb states that it was as revolutionaries and Baconians that some Puritans supported science during the Inter-

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regnum, and that as a consequence scientific organizations suffered a decline during the Restoration. The Puritan spirit of practicality, Rabb says, later assisted the growth of science in the Dissenting Academies.

The rise of Puritanism and the rise of experimental science were the two most striking features of English intellectual life from the mid-XVIth to the mid-XVIIth century. By the end of this period, for a brief while, Puritanism actually became the prevailing force in society; and after it had relapsed into nonconformity, the study of science became a dominant intellectual pursuit. Since the growth of these two phenomena took place at roughly the same time, it is natural to wonder whether there was any connection between them. The likelihood that such an enquiry will be fruitful is further enhanced by the remarkably rapid development of interest in science during the period 1640–1660. The notable advances made by the study of science during the years of Puritan rule seem to be a clear hint that there is a positive connection between them to be found somewhere. Some contemporaries certainly thought so, and in recent years the possibility has been thoroughly explored. It is with these modern investigations of the problem that this paper is concerned. After the ideas of the major contributors have been analysed, an attempt will be made to assess the problem as a whole.

Discussion of the relation between Puritanism and the growth of interest in experimental science in England can be regarded as an offshoot of the controversy over the Weber "thesis." In fact, it was with an obvious and explicit debt to Max Weber that one of the first and most persuasive cases was made during the 1930's for connecting Puritanism and science.[1] During the last twenty-five years this connection has been forcefully drawn and there have been but few and scattered murmurs of dissent. As a consequence of several articles by D. Stimson and of important major works by R. K. Merton and R. F. Jones,[2] Puritanism has come to occupy a place of considerable importance among the causes of the rise of science in XVIIth century England. So powerful was the impact of this hypothesis in the late 1930's that no full-scale refutation or qualification has yet been attempted.

At first the new hypothesis made moderate claims, but Puritanism rapidly came to hold a far more prominent place in the rise of science than had originally been suggested. This greater stress on religious factors began to appear in the works of Merton and Jones, and in reaction a few brief rejoinders rejected the hypothesis in its entirety.[3]

On the other hand G. Rosen stressed the idea even more strongly than its pioneers, when he declared that "it may be asserted without contradiction that Puritanism was one of the major motive forces of the new experimental science."[4] A more balanced assessment has not been forthcoming, while recently a full-scale refutation has been promised from the other side. Only one scholar, J. B. Conant, has attempted a qualification that allows any validity to the original thesis, but he has dealt with only one small aspect of the problem and has not tried to assess the place of Puritanism in relation to other factors.[5] Such an assessment is necessary if the problem is not to be left vaguely unresolved. Since the major treatments have all supported the link between Puritanism and science, a re-estimate is almost bound to be in reaction to that point of view. A reaction, however, need not be equal and opposite. The need seems to be for a strong qualification rather than a refutation. . . .

When attempting an assessment of the influence of Puritanism on the rise of science, it is most important to realize the differences between the aims of a Baconian, a Puritan, and a revolutionary. Their attitudes were frequently similar, but the three terms are not synonymous or interchangeable.

I

. . . It was the serious Baconian, and not the Puritan with his love of interminable sermons and learned preachers, who had the "distrust of language and hatred of words" which Jones regarded as "a unique characteristic of early modern science": [6] It is also doubtful whether Puritans were "public-spirited and humanitarian," considering their stress on the individual and their attitude towards the poor, or whether they were "materialistic." . . .[7]

It cannot be stressed too often that, in dealing with a phenomenon as complex as Puritanism, no one aspect can be treated without reference to the whole. The same is true of the "typical" Puritan, and it is illuminating to enquire as to exactly what Baxter considered "profitable." Allen suggested a convincing answer: "It was that only that seemed to tend to the salvation of himself and others. What profits is preoccupation with the next world, study of God's Word, effort for the enlightenment of souls in darkness, avoidance . . . of even the appearance of frivolity (where does Wilkins' talking statue fit in here?), faith and the love of God, sorrow for sin and effort to do better. Practically everything else, it seems, was to him unprofitable or worse." [8] Against this background a social ethos must be placed. To take one example, the belief in progress may have helped the growth of science, but before it is labelled as a Puritan concept it should be reconciled with the Puritan's deep conviction of the futility of this world. Belief in progress was a characteristic common to all Baconians, but not to all Puritans. In other words, some of the attitudes noted by Merton were attributed too easily to the influence of Puritanism.

Merton also suggested that "the sciences became the foci of social interest" after the Restoration, when "the full import of the Puritan ethic manifested itself." [9] Rather than the ethos of a largely discredited and unpopular movement, it was Charles II's patronage, the fame of the scientists and the interest of the virtuosi that now spread the interest in science. As we shall see, developments between 1640 and 1660 were undoubtedly vital, and it was certainly helpful that devout men could regard science as the search for God in Nature, but Puritanism and its ethic did not generate powerful social forces after 1660. The virtuosi, whom Merton chose to exemplify the shift to science, were usually swayed, even during the Interregnum, by an outlook very unlike that which resulted from Puritan beliefs.[10] The true virtuosi sought knowledge for its own sake or for delight, and they were "never devoted to utilitarian ends." [11] Theirs was a snobbish aristocratic movement, and its historian did not note any Puritan attitudes among its causes or motives. Seeking God in Nature was to these men at best "the common *apologia* for natural philosophy," [12] and they were far more interested in His ingenuity than His wisdom.[13] If the importance of Puritanism in the rise of science is to be found, then it must be sought among obvious Puritans in the vital period 1640–1660. It did have importance for later developments, such as the growth of the Dissenting Academies, but this must be clearly distinguished as a second phenomenon. As so often in the discussions of this problem it is the presentation or the method, not the idea itself, which is an easy prey for criticism.

One final assumption made by Merton requires examination. He stated quite simply that "Puritan principles undoubtedly represent to some extent an accommodation to the current scientific and intellectual advance . . . but to dismiss the relationship between Puritanism and science with this formula would indeed be superficial." [14] Indeed, it may be, but further explanation is needed. In this and another place Merton merely rejected the view contrary to his own with a counter-claim. Nowhere did he attempt to prove his basic contention, "that religious convictions . . . (change as) the outcome of inherent tendencies which are gradually realized in the course of time." The opposite view, that they "change only through external pressures," is not *a priori* "grievous error" or a "fundamental shortcoming." [15] In fact, it seems to be a fairly sound explanation of why the ethic was not there in Calvin, yet was supposedly there in Baxter. Calvinist theology could have approved as easily of the outlook of a mystic as of bourgeois or scientific attitudes: no inherent reason determined the outcome. Nor, for instance, was the doctrine of predestination any more similar or reassuring to the scientist's belief in immutable laws than the Catholic belief in a precise, unvarying dose of purgatory for a given sin. The more open approval of science that can be attributed to Puritanism after 1640 seems far more the result of circumstances than of inherent tendencies.

Moreover, and this is the crux of the whole problem, it seems impossible to prove that religious sanctions preceded an individual's interest in science. Some scientists, such as Boyle, seem to have been genuinely seeking the greater glory of God. But this conscious association of religion with science rarely admits of proof, and it was often merely a pious formality. Frequently, as with the virtuosi, religion provided an apologia or a sanction, but not a motive. It was important to have a religion which could perform at least this negative service, but it is doubtful whether only Puritanism would have served. Merton himself noted that Sir Francis Bacon regarded science as the glorification of God and for the "relief of man's estate." [16] Rather than seeing this as a link with Bacon's Puritan mother, this might be considered as evidence that a non-Puritan could also find these sanctions. Perhaps the word to be stressed is one that Merton himself used when he said that science was "*congenial* to Puritan tastes." [17] To avoid the implication that Puritanism was therefore the motivating force, it might be more accurate to say that some Puritan tastes were congenial to scientists.

None of these writers claimed that Puritanism was any more than one among many factors in the rise of science. But the effort spent in its establishment gave this factor a prominent place. The original careful hints of a connection given by Stimson in the early 1930's developed, despite disclaimers and moderate conclusions by Jones and Merton, into what G. Rosen in the early 1940's described as a major motive force. . . .

Only J. B. Conant, in a brief study of Oxford and Cambridge under the Commonwealth, attempted to qualify without refuting. He raised some queries that have been amplified in this essay, and he pointed the way to a reconciliation of some of the opposites that have been discussed. He questioned the importance of Puritanism as a stimulus to science because he doubted that the Oxford group of scientists contained many good Puritans, since most of them later conformed. He also noted that some of them, such as Seth Ward, even opposed the strict Puritans, who were probably far too concerned with theology to dabble in science. Conant preferred to regard the advocates of science as the young intelligentsia, who had Cromwell's backing because they had influence and tended to oppose the King, rather than because they were scientists. Yet they did gain the support of the Puritans during the Interregnum. Therefore he concluded that Puritanism was unconsciously a help to science, more because of coincidence than purpose. This is the soundest assessment yet made of the relative importance of Puritanism in the rise of science.

II

Two major problems occupy key places as indicators for a re-assessment. Though they emerge from the discussion, their implications have so far largely escaped notice. First, there is the difficulty of joining the influence of Bacon to Puritanism. The connection is made all too easily, and no mention is made of the 1621 Parliament that impeached the Lord Chancellor. Although one cannot call the House of Commons of 1621 a Puritan assembly, its hysterical treatment of Floyd amid the cry of Popery, and its measures against recusants marked it as having Puritan tendencies. There is no reason to suppose that Bacon was regarded by the average Puritan as anything more than one of the earliest in the succession of wicked royal ministers that included Buckingham, Laud, and Strafford. The fact that this attitude began to change, and did so around 1640 of all times, is surely most significant. The long interval before Bacon became influential suggests that there was no natural union between Puritanism's supposed practical bent and the Lord Chancellor's utilitarianism. In fact, such a union had to overcome, among other obstacles, Bacon's decided lack of sympathy for Puritanism, his ardent royalism and, interestingly enough, his belief that the Ancients were superior to the Moderns.[18] The change is perhaps most vividly illustrated in the person of John Pym, who as an M.P. condoned the 1621 attack on Bacon, yet twenty years later was a leading patron of Comenius, Dury, and Hartlib. The reason for the vogue of Baconian thought can be found in the crystallization of the philosophy of the revolution in the early 1640's—thanks to the inspiration of Comenius, Dury, and Hartlib [19]—and not in any basic agreement between Puritan and Baconian attitudes.[20]

Second is the more complicated problem of linking the Puritan attitude towards education and the spread of science. Recent studies have reaffirmed the pioneering work done by F. Watson,[21] who regarded the years 1640–1660 as a period of great interest and support for educational reform. In particular, W. A. L. Vincent has shown how considerable was the assistance given by the government to schools and schoolmasters. He and others also noted the numerous proposals for educational reform that poured out during the Interregnum, the support given to Comenius, Dury, and Hartlib, and the influence of Bacon and Comenius. Remarkable proposals were made: for new universities, for a national system of education and of course for revised curricula. Milton, Petty, Hugh Peters, and Hartlib were only the most famous of those who addressed themselves to the question of educational changes. Moreover, as Vincent and in more detail J. W. A. Smith indicated, the Dissenting Academies alone carried on to some extent the educational aims of the Interregnum after 1660. The significant point is that high on the list of reforms came the demand for the introduction of more scientific and practical subjects into school and university curricula.

From the standpoint of education these developments, in conjunction with the blossoming of science at Puritan Oxford, are the basis for connecting Puritanism with science. But there is another side to the picture, and it demonstrates the danger of accepting such a connection too easily without the qualification that Puritanism was primarily a religious movement, whose other characteristics were always secondary. For in the field of education, piety always came far ahead of learning for the Puritan, and when he turned from theory to action, religion was his main consideration.

Nowhere was this stress on piety better revealed than in Cromwell's two attempts to found institutions of higher learning. The abortive University of Durham and the plan for a new College at Oxford both laid heavy emphasis on Divinity. The writ for the founding of Durham made no mention of science, and stated that the University would serve the two purposes of "promoting the Gospel (and) the religious and prudent education of young men." [22] The College at Oxford was also to have been primarily a promoter of religious knowledge, and was to have gathered a "general synopsis of the true reform Protestant Christian Religion professed in this Commonwealth." [23] This is a clear indication of the real reason Puritans supported educational reform. . . .

As with the adoption of Bacon, so the interest in the new learning was a post-1640 development among Puritans who were now involved in a revolution and were seeking remedies for more than their old religious grievances. However, although Puritans now had more than merely religious interests, the primary emphasis on religious reforms remained. Nor was the Puritans' theoretical approval of science any more pronounced than that of non-Puritans. The stimulus they gave to the new learning was due not to any inherent *Puritan* tendency, but rather to the *revolutionary's* natural adoption of the convenient, ready-made, and *Baconian* philosophy.

This last sentence might well sum up the place of Puritanism in the story of the rise of science in England. For there was nothing inherent in Puritanism that necessarily led to an espousal of science. We must look away from theological attitudes to the events of a revolution to explain the indirect assistance given by Puritanism to science between 1640 and 1660. For after 1640 Puritans, who previously had thought of educational reforms only in religious terms, joined other opponents of the King's regime who supported ideas of reform that included the study of science. Approval was now reinforced by the sanction of religious beliefs. The big question is not why the Puritans approved, but why they approved so suddenly. The obvious answer is that these ideas were part of a tangible ready-made, acceptable new philosophy that revolutionaries—and the Puritans among them—adopted as one of their guides when at last they were in a position to attempt a reform of society. After 1640 the Puritans began to deal with society as a whole, not merely with their own more specific grievances. So the espousal of such ideas as the encouragement of science was the product, not of Puritanism, but of a revolution. And the men who were now encouraged were Baconians. Various independent and non-theological characteristics which have been regarded as "Puritan" only received the sanction of the Puritans when they moved from the theological wings on to the main stage of history.

Before 1640 Englishmen interested and successful in the field of science were not Puritans. Interest in the field had grown steadily thanks to other factors: the fame of discoveries and developments on the Continent; the presence of the College of Physicians, then Gresham College, and then Savile's chairs at Oxford; the fame of England's own scientists, notably Gilbert and Harvey; and the growing number of virtuosi. All these factors, none of which can be associated with Puritanism, provided direct stimuli before 1640, and were to provide some of the bases for the acceleration of interest thereafter. Gresham College was to be the meeting-place, and the virtuosi and the College of Physicians were to provide a large proportion of the scientists. The Puritans then entered the scene at the head of a revolution which acted as the catalyst for a much accelerated growth of interest in science. As Knappen and Kocher pointed out, there was nothing in Elizabethan Puritanism to indicate that this would happen. For in fact nothing inherently Puritan provided the new stimulus. It was as revolutionaries and Baconians, not as Puritans, that Bishop Williams and John Pym were united in their patronage of Comenius.

Because this was not essentially a Puritan manifestation, there were many Puritans who remained suspicious of secular learning. Moreover, the scientists themselves were rarely true Puritans, and not all of them were encouraged: Harvey has been mentioned, and Sir Thomas Browne provides the perfect example of a scientist who by personal preference remained outside the main stream of development. There was also a definite difference, as J. W. A. Smith pointed out, between the Puritan sanction of science, which was the revelation of God in Nature, and the scientist's view of his subject, typified by the Royal Society, namely, serving a practical, possibly only mundane purpose. So the Puritans, though intent on reform, satisfied religious requirements first when it came to practical encouragement.

But their revolution gave science the opportunity to grow. With numerous theories in circulation Bacon, the great home-grown philosopher of science, naturally came into his own. Especially as he was promoted by Comenius, the famous philosopher who had actually come to England and had suggested a most adoptable plan for educational reform, and by Hartlib, who was virtually a personal headquarters for ideas of reform.[24] Bacon could gain approval, despite many obstacles, because these were years of intellectual explosions, when new ideas, or old ideas revived, caught fire in revolutionary minds. Nonetheless, science was a by-product: the average soldier in Cromwell's army would hardly have had any reason to know, let alone approve, of experimental science. And however much some of the Puritans may have sanctioned and encouraged the principle, they did little consciously to further science in practice.

The contribution of the Stimson-Jones-Merton thesis has been to isolate the attitudes which favoured science in England in the XVIIth century, and to give Puritanism at least a place in the story. This place is perhaps not the one they would have assigned, but all credit is due to them for drawing attention to the problem. If a "spirit" is to be given any part, however, then it must be the spirit of greater intellectual curiosity and awareness, a sort of "Renaissance" outlook, that was manifest in England from the late XVIth century, and whose outward signs could be seen in voyages of discovery and the first colonial ventures. This in turn was an expression of England's growing wealth and strength. Puritanism itself did not stimulate scientific activity. At most, a number of individual Puritans provided the important sanction of religion, and also incidentally encouraged scientific studies through their interest in educational reform, but even in education their main concern remained with matters of religion. If direct links are to be found anywhere, they are in the sanctions and the reform of education. But even here the connections are tenuous, for they were restricted to the thought of only a few Puritans, who had an intellectual rather than a Puritan interest in new ideas in a time of revolution.

In the final reckoning, the Puritans were important because they led a twenty-year revolution, during which their benign approval, acquiescence, and occasional but hardly conscious encouragement helped to spread more quickly the growing interest in science. Puritanism cannot be regarded as a main factor or a tangible cause. Yet it would be hard to deny that its indirect help played a part of considerable importance in the developments of the time. Without this encouragement and patronage the situation would probably not have been ripe for the foundation of the Royal Society until well past 1660.[25]

In conclusion, one final effect of Puritanism's espousal of science might be noted. The Restoration unleashed a tremendous reaction against the Interregnum, the way of life it had promoted, and many of its ideals. Styles of literature, art, and living changed almost over-night. Among other results was the return of the Laudian spirit to the Universities. The Puritans' incidental approval of science and the appointments given to scientists during the Interregnum now proved to be a disadvantage. For the Universities, in reaction to the interference of the Interregnum government, returned to the pre-revolutionary situation in an attitude of determined conservatism. Educational reforms, both in theory and practice, were doomed. They were tainted, as surely as the Major-Generals, by the stigma of revolution. Interest in scientific studies was therefore greatly weakened. Almost two centuries were to pass before science could recover its full stature in the Universities and the English "Establishment."[26] In the meantime another dreaded revolution, this time in France, further delayed the recovery because it also was associated with scientific ideals.

The section of English society for which the stigma was inoperative was, of course, the nonconformist community, which was directly descended from the Puritans. Excluded from the Universities, the nonconformists established their own Academies, where the study of science continued its natural development. From these institutions came the new achievements in science, and it was there that in the XVIIIth and early XIXth centuries many of England's leading scientists, such as Priestley and Dalton, taught. Cavendish, Davy, Faraday, Herschel, and Rumford were also among the great scientists who worked outside the Universities.

Meanwhile, the Universities and the Royal Society passed through a dismal period. After the impetus that had been generated before 1660 died away, scientific studies and achievements lost their prominence.[27] There were various reasons for the decline: England's XVIIIth-century complacency, the overawing stature of Newton, the changed interests of the virtuosi, and many more. But the reaction after the Restoration was among the most effective hindrances to the further rise of science in England after the age of Newton. Whether the apathy of the Universities and the Royal Society really harmed the development of science, since an alternative patron was found in the dissenting community, is open to question. What cannot be doubted is that the alienation of scientific study from the central academic tradition was in no small measure due to the reaction of the Restoration against the ideals of the revolutionaries. The alternative patronage provided by the Dissenting Academies in the two succeeding centuries was the final heritage of the Puritans' incidental approval of science during the years of the Great Rebellion.

NOTES

[1] See R. K. Merton, "Science, Technology and Society in Seventeenth Century England," *Osiris,* IV (1938).

[2] The first hint came in Stimson's article, "Dr. Wilkins and the Royal Society," *Journal of Modern History,* III (1931), which she followed with: "Puritanism and the New Philosophy in XVIIth Century England," *Bulletin of the Institute of the History of Medicine,* III (1935); "Comenius and the Invisible College," *Isis,* XXIII (1935); "Amateurs of Science in XVIIth Century England," *Isis,* XXXI (1939); and her book *Scientists and Amateurs,* New York, 1948. Meanwhile R. F. Jones had published his book *Ancients and Moderns,* St. Louis, 1936, and an article, "Science and Criticism in the Neo-Classical Age of English Literature," *Journal of the History of Ideas,* I (1940). Merton, before his "Science, Technology . . . ," wrote an article, "Puritanism, Pietism and Science," *The Sociological Review,* XXVIII (1936). The relationship between Protestantism and the rise of science throughout Europe has also been discussed, but is a problem too large for this essay. For a recent argument that the connection existed in Europe in general, see R. Hooykaas, "Science and the Reformation," *Cahiers d'Histoire Mondiale,* III (1956). It is argued in a fashion similar to Merton's and is followed in the same issue by interesting "critical comments" by R. H. Bainton.

[3] M. M. Knappen, *Tudor Puritanism,* Chicago, 1939, pp. 478–80; P. H. Kocher, *Science and Religion in Elizabethan England,* San Marino, 1953, especially pp. 14–19; and M. H. Curti, *Oxford and Cambridge in Transition,* 1558–1642, Oxford, 1959, pp. 247–9 and Note M, 287–8.

[4] "Left-Wing Puritanism and Science," *Bulletin of the History of Medicine,* XV (1944).

[5] J. B. Conant, "The Advancement of Learning during the Puritan Commonwealth," *Proceedings of the Massachusetts Historical Society,* LXVI (1936–41).

[6] *Ancients* . . . , p. 94.

[7] *Ibid.,* p. 92. For the Puritans' social policies during the Interregnum, see M. James, *Social Problems and Policy during the Puritan Revolution 1640–1660,* London, 1930.

[8] *English Political Thought* . . . , p. 282.

[9] "Science, Technology . . . ," p. 454.

[10] W. E. Houghton, "The English Virtuoso in the Seventeenth Century," two articles in the *Journal of the History of Ideas,* III (1942).

[11] *Ibid.,* p. 54.

[12] *Ibid.,* p. 195. The italics are mine.

[13] R. S. Westfall, *Science and Religion in Seventeenth-Century England,* New Haven, 1958.

[14] "Science, Technology . . . ," p. 440.

[15] *Ibid.*, p. 458.

[16] *Ibid.*, p. 447.

[17] *Ibid.*, p. 449.

[18] For this last point see C. C. Gillispie, *The Edge of Objectivity*, Princeton, 1960, p. 74. [While Bacon is one of the originators of the idea of progress, he often used the example of the pre-Socratics, Democritus, Epicurus, and Leucippus, to criticize contemporary Aristotelians. The Editor.]

[19] H. R. Trevor-Roper, in "Three Foreigners and the Philosophy of the English Revolution," *Encounter*, XIV (1960), has shown the importance of Comenius, Dury, and Hartlib, and, through them, of Bacon, for the development of the philosophy of the revolution.

[20] This paper tries to distinguish between phenomena which seem to have been confused, but does not attempt to explain this confusion. Some of the reasons may emerge in passing, yet it is worth noting that some close similarities between Baconianism and Puritanism tend to hide the differences between them: the similarity in their styles of expression, their coincidence in time, and their unity and collaboration in opposing the existing order. The author hopes to investigate this problem further at a later date. It would be interesting to see the results of further investigation of these and other misleading similarities.

[21] See especially F. Watson's article "The State and Education during the Commonwealth," *English Historical Review*, XV (1900).

[22] See pp. 522–3 of the writ as printed in W. C. Abbot, *The Writings and Speeches of Oliver Cromwell*, Vol. IV, Cambridge, Mass., 1947, pp. 522–8.

[23] Quoted by M. James, *Social Problems* . . . , p. 318.

[24] An excellent brief description of the vital role played by the principal "liaison men" at this time can be found in Stimson's "Hartlib, Haak and Oldenburg: Intelligencers," *Isis*, XXXI (1940).

[25] Another controversy, this one about the earliest origins of the Royal Society, has helped to reveal exactly how the interest in science grew so rapidly during the Interregnum. This is a dispute about the relative importance of the propagandists of science. R. F. Young, for instance, laid great stress on the influence of Comenius in *Comenius in England*, London, 1932, and in "Comenius and the Invisible College," *The Teacher of Nations*, ed. J. Needham, Cambridge, 1942. This emphasis Stimson questioned in "Comenius." R. H. Syfret, "The Origins of the Royal Society," *Notes and Records of the Royal Society of London*, V (1948), reassured the importance of Comenius, but put principal emphasis on the activities of Haak. She in turn was criticized by G. H. Turnbull, "Samuel Hartlib's Influence on the Early History of the Royal Society," *Ibid.*, X (1953), who suggested that Hartlib was more important than either Comenius or Haak. The main interest of this discussion has been in its detailed revelation of how interest in

science was stimulated by these propagandists and by links with the Continent during the years that England was ruled by the Puritans.

[26] A short but excellent survey of the status of science in England during the XVIIIth and XIXth centuries can be found in Sir E. Ashby, *Technology and the Academies*, London, 1958, pp. 1–66.

[27] A recent investigation of the loss of prestige suffered by science at the end of the Seventeenth Century has been made by M. Espinasse. "The Decline and Fall of Restoration Science," *Past and Present*, No. 14 (1958), pp. 71–89. It is interesting that she has noted (p. 87) that dissenters were quite common in the Royal Society only during the early years after the Restoration, when English science recorded some of its greatest achievements.

BERNARD DE FONTENELLE: IN DEFENSE OF SCIENCE *

Leonard M. Marsak

Although well aware of the practical uses of science for war, industry, and exploration, the French philosophers of the eighteenth century emphasized its intellectual content. Bernard de Fontenelle hoped that the scientific methodology would help to emancipate the mind from ignorance and error. His view of science as a new way to achieve older, humanistic goals is set forth by the author.

I

Much of the discussion in recent years about the relation of science to the humanities has centered upon the effect of science on literature. Too little has been said about the reverse effect that provided science with a place among the more traditional disciplines at the time it was first being formulated. It was no accident that Bernard de Fontenelle, a humanist and *litérateur*, should have been chosen as secretary of the Aca-

* Reprinted with permission of the editor, from the *Journal of the History of Ideas*, Volume XX, 1959. See H. Butterfield, *The Origins of Modern Science*, N.Y., 1950, p. 95; J. Bronowski, *Science and Human Values*, New York, 1959; and Leonard M. Marsak, *Bernard de Fontenelle: The Idea of Science in the French Enlightenment*, Philadelphia, 1959. [Editor's note.]

démie des Sciences at its renewal in 1699, not to act as a popularizer of science as many have believed, but to serve as its critic and to write its defense. Each revival of poetry has called forth its defenders, for example Sidney, DuBellay, Wordsworth, and Shelley. The arrival of science also required a spokesman to explain its meaning and describe its uses. The value that Fontenelle attached to science linked it securely in his time to the humanities, and we can argue that this link accounts for its acceptance in eighteenth-century France, much more than any hoped for utility.

The growing emphasis of recent scholarship upon the utilitarian aspects of seventeenth-century science should not be under-valued, coming as it does after a long period in which science was thought to develop *in vacuo,* apart from the social currents of the times.[1] Bacon was not alone in his recognition of the material contribution that science could make to mankind. It was almost fashionable for those who came after him to express hope for the better life. We know that Boyle as well as Bacon spoke for the uses of science, although neither one neglected to emphasize its purely intellectual aspects. The imaginative Bishop Wilkins, directed his attention on numerous occasions to the practical uses of science. Even the great Newton, was sufficiently motivated in this direction to advise a young traveller to keep his eyes open for the useful things being done abroad that might be of interest to England.

The French did not have to wait for the encyclopedists, and the so-called "Introduction of Baconianism into France" to appreciate the utilitarian motive. In his preface to Galileo's mechanics Mersenne argued that mathematics ought to be linked to engineering, for the benefit of both; the constitution of the Montmort academy required practicality in its researches, and Huygens emphasized it in his plan for the projected Académie des Sciences.[2] That Colbert had the thought of its usefulness in mind when he argued for the Academy is significant, and not at all surprising, and when the Academy was reorganized in 1699 its new secretary continued to voice the hope that science could be made to benefit the country. He said this at length in his "Preface on the utility of mathematics and physics." More to the point, however, are the numerous references in the History of the Academy to the practical problems that were set for it by the government, especially those having to do with navigation.

However, we must take care not to overemphasize values that an earlier age qualified. Although Fontenelle stressed utility in the preface just mentioned, it was not to be achieved at the expense of pure science. There is never any doubt in this work that he viewed utility as a by-product of science, and not the other way around. The light cast by the disinterested search for truth might shine by reflection upon our practical problems, but for Fontenelle and others it was the mind's quest for knowledge that justified science. It would seem that Fontenelle's preface, like Réaumur's "Mémoire" of 1716, consciously, and, perhaps it was hoped, subtly emphasized the utilitarian aspects of science, in order to secure funds for basic research from an ungenerous government. This, after all, is a common situation with which we are familiar today.

Moreover, Fontenelle gave evidence of his fear that a practical-minded government would throttle scientific endeavor. He has told us in the History of the Academy that the Marquis de Louvois, who became its protector in 1683, "wanted the Academy to apply itself principally to works of a tangible and immediate utility, which would contribute to the king's glory." [3] That is precisely what happened to the Academy before 1699. It was used by Versailles to solve problems of war and siegecraft, and gambling. Its decline between 1683 and 1699, due partly to this treatment, but also to the revocation of the Edict of Nantes, the impoverishment of the nation by Louis' wars, and the susceptibility of the scientists to play at being courtiers, finally occasioned its renewal over which Fontenelle was to preside, so that he could not have been ignorant of the danger of government control. He recognized that science had become big and expensive and might have to be supported by the government treasury, but he agreed with the Abbé Bignon that the Academy should be kept apart from the crown for the benefit of science.

We would be closer to a true view of the relation of theory to practise if we understood the dependence of science on craft. This is how Fontenelle saw and valued the relationship, happy that the arts and crafts could provide valuable information for science, and lessons in methodology as well. He recognized the debt that chemistry owed to pharmacy, botany to medicine, and hoped that the union between science and craft would continue to be fruitful. It was with this purpose in mind that the Academy undertook a description of the arts at its renewal, so that those scientists who were unable to observe the artisans at first hand would find a description of their instruments and activities in the History.

The real meaning of science for Fontenelle, therefore, lay not in material improvement, nor even in the scientist's growing knowledge of the processes of nature, although these achievements gave added value to his activity, but in the gradual emancipation of the mind from ignorance and error that a newly formulated methodology made possible. Those susceptible to the latter process, Fontenelle sensed, were creating a new way of life for themselves that was indeed revolutionary in its implications. Nowhere is the meaning of science made more clear, and its value so appreciated, as in that series of "lives of the scientists" that we know as the "Eloges." [4]

II

That metaphysical speculation and theological argument were pointless was a cardinal principle of Fontenelle's thought, but he also considered them unbefitting the creative intelligence. We are told that Régis, "disgusted with the excessive length of a lecture on the hour of the institution of the Eucharist," turned in despair to the Cartesian philosophy. Such a pattern of behavior is described many times over in the *éloges,* with the implication that the mind's impatience with endless disquisition is a sure sign of sophistication. The mind must be fed in a manner suitable to its capacity. However, care must be taken to preserve its freedom of action, for any authority to which it submits will stunt its growth. Hartsoeker finally learned that lesson.

"His philosophy teachers were Cartesians as committed to Descartes as the scholastics had been to Aristotle. They had simply changed masters. Hartsoeker adopted an extreme Cartesianism which he gradually abandoned. We must always admire Descartes but follow him only occasionally." [5]

Although Cartesianism offered more substantial nourishment than scholastic philosophy, it had no more right to command obedience than the system that preceded it.

The weaknesses of system building, and its hostility to the purposes of the Academy were set forth succinctly in Fontenelle's *éloge* of Malebranche where he explained that:

"Up till now we have recognized Father Malebranche as a metaphysician or theologian, and in these two capacities he would be a stranger to the Academy which would rashly exceed its limits if it touched on theology, and which abstains altogether from metaphysics because it appears too uncertain and too contentious, or at least of too little use." [6]

But Malebranche was also a geometer which entitled him to a place in the Academy. So long as one's generalizations did not limit one's capacity as scientist or mathematician, Fontenelle entertained no objection to the presence of metaphysicians in the Academy, but his genuine praise was offered to those who were truly experimentalists, Du Hamel for example, who entered into questions of a general nature only regretfully. Of course, Fontenelle did not intend to banish theoretical considerations from science, but they were to be consistent with the materials of the discipline, following upon the facts, and not preceding them.

It was this respect for the discipline that characterized science, according to Fontenelle, and required the practitioner to cultivate a personal disinterestedness that was rare among human beings, and, perhaps, never to be found prior to that time except among saints and mystics. That a secular subject matter could provoke a seriousness and dedication that religion has commanded was perhaps for Fontenelle the most significant feature of science. Anyone, artistocrat as well as bourgeois, could fall prey to the "new humanism," but just as soon as he did so, he functioned in a totally different capacity, one that precluded self-interest, profit, gain, self-advertisement, or so Fontenelle thought. (Perhaps in this regard the "new humanist" was to be distinguished from his literary predecessors who appeared never to have acted without the spur of fame.) How different Renau and the Marquis de Dangeau were from the idle aristocracy. Fontenelle makes another example of Tschirnhaus who experienced something like a conversion that allowed him to dedicate himself to science with a seriousness that was alien to his class.[7] It was with a sense of professional responsibility that Guglielmini turned to his task as "Surintendant des Eaux," displaying a seriousness of purpose and dedication to the public that could be called by no other name than professional morality.

In a land where even literary genius had to pay court to the king, the appearance of a morality that dictated allegiance to something other than power was nothing short of revolutionary. That such an attachment was startlingly new and therefore had its dangers was quite clear to Fontenelle. Of Bourdelin he said:

"It is rather unique that in a country where all professions, no matter what they may be, are transformed into that of the courtier, Bourdelin remained a doctor, and pursued only his métier at the risk of not paying court [to the king]." [8]

The scientist was no longer a virtuoso in the eighteenth century, but one who took on dignity to the extent that his personality became "task-oriented."

The task very often required of the scientist feats of prodigious labor, exposure to inclement weather, and fortitude to resist ill health that resulted from his activities. As Professor Butterfield has said, the scientist emerged as a hero in the *éloges*. Fontenelle described the cost to the astronomer of his dedication to truth when he eulogized Maraldi:

"He was only too happy when he could remain in his study. Those long, night-time vigils that scholars and poets like to talk about are nothing in comparison with those kept in the open air and at all seasons to study the sky. Maraldi's health was ruined by such rigorous work."

Fontenelle pointed out that despite such great personal cost to Maraldi, he gladly made his results available to other scientists. After all, knowledge belonged to every man, the world could assume, although this assumption was made in actuality by only the happy few.

What benefit then, if any, derived to the scientist from his application to work? The rewards of science, like those of religion, Fontenelle explained, were of the spirit. He told of his pride in knowledge in the *Plurality of Worlds* and then went on to say that the "Vortices" cured one of ambition and anxiety. How delicious the state of tranquillity was to Fontenelle and to the scientists he praised is made apparent in the following quotations. Of Reyneau, Tschirnhaus, and Varignon, Fontenelle said:

"(Reyneau) rid himself of all business matters, especially all manner of intrigue, and he valued very highly the advantage, so little sought, of being a nobody.

. . . . . .

True philosophy had entered his heart and endowed him with this delicious tranquillity which is the greatest and least sought after of goods.

. . .

I have never seen anyone who had a greater conscience, by that I mean anyone who was more concerned to fulfill the spirit of his duties, and less concerned to satisfy appearances." [9]

That such feeling did not prevent petty jealousy and internecine warfare in the Academy is quite clear to even the casual observer, but this fact should not permit us to underestimate the importance of the stated ideal.

It would be unfortunate, however, if we were to allow Fontenelle's use of the word "tranquillity" to mislead us. He himself has so often been charged with being an egocentric, interested only in his own mental comfort, that it would be possible to read this value into the state of mind that he described. Happily, the accusation is true neither of Fontenelle nor of the scientists he undertook to praise. It should be clear from our discussion that it was not a state of personal comfort that Fontenelle valued, but the very opposite of egocentrism, the disinterestedness, unconcern for petty advantage, largeness of spirit that science made possible for its practitioners. That this morality was not only a matter of personality but was thought to derive from science itself is made clear by the following excerpts from the *éloges* of Maraldi, Du Hamel, and Varignon.

"His character was that which the sciences form ordinarily in those who make it their sole occupation: seriousness, simplicity, righteousness. One easily saw that his humility was not a pose but a feeling founded on science itself.

His character was as simple as his superiority of mind could require. I have already given this same praise to so many persons in this academy that one would believe the merit pertains rather more to our sciences than to our savants." [10]

It can be seen finally that a whole new breed of men had been created, when Fontenelle said in praising Leméry that, "this praise pertains rather generally to this small, private group of men that the business of science separates from the majority of mankind." Whatever selflessness Fontenelle discovered in the scientists of his generation he was justified in describing as high moral behavior. It bore a certain resemblance to the behavior of saintly persons; so that the new humanism that Fontenelle set out to praise was not without religious values.

However, if science has the capacity to induce morality, there is a quality of mind upon which science itself depends, and that is mental curiosity. Far from praising peace of mind, Fontenelle held it accountable for a lack of science among the Chinese whom he believed were tranquil by nature. True science, he opined, required an unquiet state of mind, an incapacity to be satisfied. Fontenelle very clearly distinguished between the moral qualities induced by science, and the state of mind necessary to its practice. Having done that, he affirmed no contradiction between the contentment proceeding from the former state, and the divine discontent that was a condition of the latter.

We are not surprised that Fontenelle attached a morality to science when we remember that he viewed the pursuit of knowledge with almost religious fervor. He has told us that "physics becomes a kind of theology when it is pursued correctly." [11] According to Fontenelle the subject matter of science testifies to the intelligence and power of the Creator. Therefore we might say that it becomes the religious duty of the scientist to investigate nature. The creation of a comprehensive body of knowledge that would be an accurate description of nature might be the goal of science, but such knowledge would yield more than power. "Nature is never so admirable nor so admired as when it is known." [12] Discovery would afford us the pleasure of contemplation and admiration which is akin to that of worship. Let us note that the aesthetic satisfaction to be derived from science is not extrinsic to it, according to Fontenelle, but an essential component of it.

However, if Fontenelle accorded reverence to knowledge, he attached an even greater value to the thought that won it. In a burst of optimism he went so far as to relate thought to virtue, saying, "Whoever has the leisure to think discovers nothing better than to be virtuous." [13] As a rule, however, he needed no such justification for thinking, for the mind's activity was itself a positive good. It was the mind that had made the greatest discovery in science, the art of discovery itself, for this is the device by which the mind implements its activity, the device that goes under the name of method. The method of science, which is the keystone of its whole structure, according to Fontenelle, is no more than mind rightly conducted. Conversely, method is given credit for having raised the mind to new levels of excellence and productivity. In describing the utility of mathematics, Fontenelle concluded the list of benefits to be derived from it as follows:

"Finally, mathematics has not only produced for some time now an infinity of truths of its own kind, it has also produced rather generally a refinement in the minds of men more precious perhaps than all these truths." [14]

There is no doubt that Fontenelle viewed the mind as the ultimate beneficiary of science, and he must be given credit for having helped to establish that value in France.[15]

The mental, moral, and aesthetic values that Fontenelle ascribed to science were central to his thought and to the life of science in his time. Without them Fontenelle could not have perceived the beauty of science. With them he could cultivate the quality of disinterestedness that alone makes science possible. Although these values were attached to the matter of science, according to Fontenelle, quite clearly they had their roots in the long literary and religious experience of Western Europe. Indeed Fontenelle insisted that a background in the humanities provided rather specific qualities necessary to science. Speaking to the Académie Française in 1741, near the end of his professional career he touched on the importance of language.

"The spirit of order, clarity, and precision necessary in this delicate work will be the key to the most abstruse sciences provided one applies it correctly; and I acquired here the first tincture of this spirit that allowed me to discharge my new duties [as secretary of the Academy of Sciences]. Thus, gentlemen, it was the Académie Française that formed me first of all." [16]

The acknowledgement that literature assisted in the development of his scientific capacities, that qualities of clarity, order, and precision, so necessary to science, should have derived from his concern with language is what renders Fontenelle a surprising phenomenon to us. But Fontenelle was not unique in his time. Maupertuis and d'Alembert were both equally accomplished as mathematicians and essayists. Buffon was of course a master stylist, and La Condamine was not only a physicist, but a writer of agreeable verse. The "New Philosophy" seems to have grown in the bosom of the older disciplines, a fact very often overlooked when the reverse effect of science on literature, history, and philosophy is described.

There is a more specific case in which science was indebted to the humanities. It may be remembered that in 1694 the Dictionary of the Académie Française called for expunging scientific terms from the language. Fontenelle appreciated the extreme sensitivity of his compatriots to language, but realized the necessity of creating a scientific language if science itself was to progress. It was his glory that he helped to do so without creating monstrosities of jargon and style. Speaking before the Académie Française in 1741, after the battle had already been won, Fontenelle explained his rôle as literary pioneer for science:

"When the Académie des Sciences was renewed . . . (The Abbé Bignon) desired to see the taste for science spread in society. Science had used, as in ancient Egypt, a certain sacred language understood by its priests alone. The new director wished it to speak the common language, as far as possible, and he did me the honor of making me its interpreter."

Fontenelle helped to fashion a "common" language for science and it is possible to say with equal assurance that its creation was a direct contribution to science itself.

Of course, the attention to language had that other object in mind, popularization. The traditional French sensitivity to language made a suppleness, clarity, and precision of exposition necessary if the task was to be fulfilled. Fontenelle was describing his rôle as secretary of the Academy when he spoke of it in his *éloge* of Du Hamel:

> "The Academy needed a secretary who understood and could speak the languages of the different savants, be their interpreter, and give a certain clarity to their writings, and finally who was disinterested and exempt from all partiality."

The popularization of science in the eighteenth century had widespread effects and is a subject all its own, but this much may be noted, that it had no small importance in the growth and ultimate acceptance of science itself. Fontenelle clothed science in the language of the humanities, and it was this achievement that won a place for it in the public consciousness. Montesquieu, writing in 1725, thought the *Plurality of Worlds* more useful than other more serious works, "because it was the most serious that the majority of people were in a condition to read, . . . and often one says some very important things while joking." There were many others who applauded Fontenelle's work of popularization, for it was seen that in addition to educating the public a friendly environment was being created that would ease the task of the scientists. Propaganda for science went hand in hand with popularization. Fontenelle had ceased making pleasantries when he wrote the *éloges*, but they, like the *Plurality of Worlds*, succeeded in capturing an audience measurable by the twelve editions of his complete works that appeared during the course of the eighteenth century.

We must remember that Fontenelle did not intend to paint a series of portraits in the *éloges*, but rather to write a critique of the lives of the scientists in the manner we have described. These "lives" were included in the successive numbers of the History of the Academy before they were republished in a separate volume, so that we must consider them within the context of the History, and with the purpose of that publication clearly in mind. Fontenelle explained in the "Préface" of 1699 that the History, as distinguished from the Mémoires, was designed for those with only a limited knowledge of mathematics and physics. Such a distinction it was hoped would have the following advantage: "That the work of the Academy would become better known, and that the taste for science would be spread more widely." Indeed Fontenelle was picked as secretary of the Academy with this object in mind. We can assume, therefore, that Fontenelle wrote the *éloges* with the purpose also of propagandizing for science. The Abbé Trublet tells us that he was eminently successful in this enterprise. "The taste for science being more widely spread, the savants have become more esteemed, more highly considered, more sought after." Let us state once again that it was science itself that was being promoted, not public education, and not, as several commentators have suggested, Cartesianism or the rising bourgeoisie. Although one commentator has said that "We cannot read the histories of these illustrious dead, without being seized by the desire to follow in their footsteps," it is safe to say that Fontenelle succeeded not so much in winning large numbers to the practice of science as he did in winning many to its cause.

The rôle of spokesman for science served one other function that few have recognized. Fontenelle spoke directly to the scientists when he explained the principles of science, when he established its link with the humanities, when he argued for the whole man. D'Alembert praised Fontenelle in the *Encyclopédie,* "for having taught the savants to lift the yoke of pedantry." Fontenelle taught the savants themselves that they could remain *"hommes d'esprit"* while cultivating the sciences. The whole man, he believed, need never be sacrificed to the demands of specialization.

III

In stressing the importance of literature to science, I should not like to suggest that science is simply a product of the literary impulse gone astray. To be sure Fontenelle recognized the distinctly new contribution that science could make to thought and life. Indeed, science was made to serve as the basis for his idea of progress. But Fontenelle never severed the connection with his roots in life and thought as some of the materialist *philosophes* did. He refused to do so out of conviction as well as feeling. For one thing, he believed that the historical development of science linked it with the humanities with which he found it to be consistent. For another, Fontenelle shared none of the facile optimism of the eighteenth-century *philosophe* who believed in the unlimited perfectibility of man. Although social morality could improve with civilization, he believed that the morals of the individual would remain forever the same. Just so long as man's passions directed him would his perversity inflict evil upon the world. The tragic view of life that is found in Pascal, and returned to us by Dostoievsky, is the source of Fontenelle's pessimism.

It would be a mistake however, to over-emphasize or misunderstand Fontenelle's pessimism. If man is a reed, bending in every direction before the gusts of his passions, he is still, as Pascal described him, a thinking reed. If Fontenelle viewed the promise of science with something less than complete optimism, nevertheless he valued its achievement as an expression of man's highest mental aspiration, the pursuit of truth. Moreover, he discerned a value in the practise of science that allowed him to attach a high morality to it. Attributes of selflessness and dedication to knowledge distinguished the scientist from the self-interested individuals who comprise the majority of mankind, so that the intellectual emerges as the hero of the age. If the nineteenth and twentieth centuries have held up the businessman and engineer for emulation, it would not be an exaggeration to say that Fontenelle spoke for the civilization of the Enlightenment when he put the scientist in the niche that had formerly been reserved for the artistic creator of the Renaissance or the saint of the high Middle Ages. By creating such a secular sainthood Fontenelle sought not only to define science but to peer into the man who practised it, and to value him as a man. He was, in short, practising the old and honorable craft of *moraliste*, a fact that the eighteenth century found to his credit, and for which we must do him honor.

Although we question today the relatedness of science and the humanities, it seemed hardly debatable to Fontenelle that the glory of science was to be found in connection with man's mind and morality. Being closer to the source of science, and having profited by a humanist education, he perceived with much greater ease than we do that science was what George Sarton has called "the new humanism." Although it was a distinctly different mode of thought from the traditional humanities, it was simply the latest of man's creations, among others, that hoped to define his relationship with the universe, with society, and with himself.

NOTES

[1] See G. N. Clark, *Science and Social Welfare in the Age of Newton* (Oxford, 1949), and H. Brown, "The Utilitarian Motive in the Age of

Descartes," *Annals of Science,* I (1936), for the social relations of science in the seventeenth century.

[2] See H. Brown, *Scientific Organizations in Seventeenth-Century France* (Baltimore, 1934), 75 ff.

[3] *L'Histoire de l'académie des sciences,* 1683, I, 394. Translations here are mine. [Ed.]

[4] Fontenelle set a precendent in the "éloges" that all succeeding secretaries of the Academy have wished to follow. Many of them, Condorcet, Flourens, J. L. F. Bertrand, de Broglie, to name a few of the distinguished ones, have striven with success to maintain a high level of style and content in their eulogies so that the entire series of them serves as a valuable reader in French science.

[5] "Eloge de Hartsoeker," VII, 213.

[6] "Eloge de Malebranche," VI, 420.

[7] On the other hand Chirac had risen from poverty to a position of eminence in science, and eventually to a patent of nobility. Science, like the Church before its time, and the army after it, seemed to be "la carrière ouverte aux talents."

[8] "Eloge de Bourdelin," VI, 96.

[9] "Eloges de Reyneau, Tschirnhaus, Varignon," VI, 260; VII, 161 and 300.

[10] "Eloges de Maraldi, Du Hamel, and Varignon," VI, 173; VII, 350 and 160.

[11] "Préface sur l'utilité des mathématiques et de la physique." VI, 70.

[12] *Ibid.,* 72.

[13] "Eloge de Homberg," VI, 398.

[14] "Préface de l'histoire de l'académie des sciences," VI, 2.

[15] Montesquieu paid Fontenelle the tribute of imitation when he listed the benefits of science. The difference between savagery and civilization, he declared, is made by the arts and sciences. The Indians would never have been conquered if they had possessed them, as Fontenelle suggested in the *Dialogues des morts.* But the real benefits of science accrue to the mind. Montesquieu lists them as the satisfaction of the urge for self-improvement, and the satisfaction of our natural curiosity, the acquisition of a method for study, the pleasure of study itself, and the satisfaction of the urge to benefit society. Fontenelle is mentioned as a source for the idea of science in Montesquieu.

[16] "Discours prononcé par Fontenelle, doyen et directeur de l'Académie Françoise, à l'ouverture de l'assemblée publique du 25 août," I, 168.

SCIENCE, EDUCATION, AND NAPOLEON I *

L. Pearce Williams

The following article describes the decline of science under a government too interested in its practical applications. The Empire focused attention on the humanities, which seemed less of a threat to Napoleon's military dictatorship than the critical attitude that science encouraged. Professor Williams teaches the history of science at Cornell University.

The Napoleonic coup d'état of 18 *brumaire an* VIII (9 November 1799) was hailed in France as signifying the end of the revolutionary turmoil which had racked the country for a decade. Disappointed in their dreams of true liberty, assailed on all sides by the forces of reaction, suffering from a severe inflation together with the inefficiency and corruption of new institutions and inexperienced administrators, the French people with few exceptions saw in Napoleon the man who could cure the ills that afflicted the Republic and usher in a new era of peace, order, and prosperity. That the curative measures which Napoleon would take might lead to a despotism more absolute than that overthrown by the insurgents of 1789 was a matter of relative indifference to most. The revolutionary fever had run its course, and the fanaticism of the early years of revolution, with its underpinnings of hope and faith in the imminence of the millennium, had long since been dissipated by the guillotine, the Chouannerie, and the Vendée. The *Ancien Régime* seemed after all to have had some virtues, and the criticisms leveled by the *philosophes* against the old order lost trenchancy when viewed against the failures of the new regime. In short, the road to reaction was evident: the Napoleonic despotism was modeled on the old order, with a few concessions to the positive accomplishments of the new.

The area of public education is a particularly interesting one in this transition from an exhausted republic to a dynamic despotism. The

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ideals of a society are often most clearly seen in the provisions made for training its future citizens, and the philosophy underlying this training reveals the values on which a particular society is built. For both the historian of France and the historian of science, the study of the educational history of the Revolutionary and Imperial periods is a rewarding one. The Napoleonic reforms of public education created institutions and methods still influential in the France of today. Both the Republic and the Empire carried out a revolution in educational practice by making the sciences a permanent part of the curriculum and by creating institutions which have influenced systems of education all over the world. Yet there is a profound gulf between those philosophies of education which motivated the creation of the schools of the Republic and those of the Empire. The Republican ideal was a nation of free men who, through knowledge of the universe and the society in which they lived, could deliberate coolly on matters of national interest and arrive at policies through the exercise of reason and intelligent debate. The study of the sciences was the very cornerstone of this approach, for the harmony and order which the sciences revealed justified the assumption of the adequacy of reason on which the entire philosophy was built.[1] It is the purpose of this article to examine the role of science in the Napoleonic educational system and, if possible, to estimate the effects of the Napoleonic reforms on the development of modern French science.

By 1800 there was little doubt that the educational system of France was profoundly in need of reform. Although the law of 3 *brumaire an* IV (26 October 1795) had been quite specific and detailed as to the organization of the curriculum of the *écoles centrales,* the departmental administrators were either unwilling or unable to enforce the terms of this law. Instead of the students following the order of the courses as prescribed by law, they were allowed complete freedom in their choice of subjects and in their attendance. The Inquest of *an* VII (1798) revealed that in fifty-eight of the eighty-three *écoles centrales* reporting, no specific order of courses existed and that the student was able to attend any which attracted him. Moreover, if the student became bored or if the subject became too difficult, there was nothing to prevent his leaving that course and picking up another in mid-term. The result was an almost complete lack of coherence in the educational experience of the individual.

Just as important as the educational anarchy which characterized the *écoles centrales* was the inability of the central and local governments to meet their financial obligations to the teachers in these schools. While the government of the Directory was in a constant state of financial embarrassment, administrative bungling and inefficiency also played an important part in this failure to pay public servants. At Paris, for example, there were two *écoles centrales* which never were opened; nevertheless the faculties received full salaries until the reorganization of the Ministry of the Interior under Napoleon brought this matter to Chaptal's attention.

The Napoleonic reforms, however, were not restricted simply to eliminating these faults in the educational structure, but went far deeper than this, challenging the basis of the educational philosophy upon which the *écoles centrales* had been built. To the *Idéologues,* the architects of the schools of the Directory, the aim of education was to create enlightened citizens, and their entire concept of public instruction was based on the "natural" liberty and equality of men. To the Napoleonic government, such aims were but the vaporings of metaphysicians who knew nothing about the realities of the world in which they lived. The scheme of the *Idéologues* was dismissed by Chaptal with the words, "It is impossible to teach the art of law-making." [2] The Napoleonic state was based on the proposition that one man—Napoleon—was to bear the entire burden of government, and that citizens in the ideological sense of the word, were not only superfluous but dangerous. Napoleon desired obedience, not criticism or discussion. The function of education in this state was correspondingly redefined.

> The principal goal of education ought to be to give everyone the knowledge necessary for him to fulfill the functions in society to which he is called.

The hierarchical nature of Napoleonic France thus demanded a similar hierarchy of studies. For those who were to perform the menial tasks of society, the elements of reading, writing, and arithmetic, together with the principles of religion and propaganda supporting the Napoleonic regime, were sufficient. These secondary schools were for those who would enter the various useful professions, and secondary education was, therefore, preparatory to entrance to the professional schools. This preparatory education, however, was conceived in a very narrow way. The first article of the *arrêté* of 19 *frimaire an* XI (10 December 1802) set out the basic curriculum and revealed the goals of Napoleonic education: "In the *lycées,* Latin and mathematics will be the essential subjects taught." [3] The study of Latin letters (later modified to include history and French literature as well) insured the future administrator and civil servant of a familiarity with good style and with the minimum of culture necessary for the performance of public functions in this heroic age; the study of mathematics assured Napoleon adequate officer material for the pursuance of his military programs in Europe. The emphasis was on the humanities, for, of the seven years which the student spent at the *lycée*, only three at the most were devoted to mathematics. The other sciences found little or no place in this system. Out of forty-four *lycées* organized by 1808, only eight offered courses in physics, chemistry, or natural history, and these courses were not well attended. The distribution of prizes given to students in Paris, where under the Directory the sciences had flourished, gives some idea of the role science played in the Napoleonic educational system. In 1809, 169 prizes were given in classics and belles-lettres; 21 were awarded in the three courses in mathematics which treated this subject from arithmetic to the elements of differential calculus; no first prize was given in physics because "The examiners . . . , feeling that there was no paper worthy of a first prize, awarded the second prize to M. Gazan, student at the Lycée Impérial." In 1810, 148 prizes were given in belles-lettres, 3 in physics and chemistry and 13 in mathematics; 1811, 151 in belles-lettres, 6 in physics and chemistry and 14 in mathematics; 1812, 154 in belles-lettres, 3 in physics and chemistry and 15 in mathematics.

The study of mathematics was only slightly more widespread than that of the physical sciences. Ten out of the forty-four *lycées* organized by 1808 had no professor of "mathématiques transcendantes," which meant that instruction in this subject included only intermediate algebra. Even where there were chairs of higher mathematics, this study seems to have attracted few students.

> The students flocked to the lower and intermediate classes in mathematics; they avoided the higher branches. Plethora here and famine there; 150 or 160 students in the first group, at most a few in the second.

What were the reasons for the unpopularity of the sciences and higher mathematics? Napoleon, after all, as a member of the Institute, counted such famous scientists as Berthollet and Monge among his personal friends, and went out of his way to reward foreign scientists such as Davy and Volta for their contributions to scientific knowledge. If ever there was to be a scientific Maecenas, the Emperor of the French appeared to have all the necessary qualifications. Yet Bonaparte's love of science seemed never to carry over into the practical affairs of creating institutions and governing France. Science was a weapon to be used against his enemies, and the main reason for the teaching of science was to provide subjects who could fill places in the armed forces and put their knowledge to use on the battlefields. Thus the course in physics and chemistry offered at the Lycée de Dijon was required for those students who "se destineront aux Ecoles militaires"; at Pontivy, it was simply assumed that those who followed the course in mathematics would enter the army. In Paris, at the Lycée Impérial, the student was forced to choose between "la carrière civile" and "la carrière militaire." If he chose the former, his scientific education ended with a course in plane geometry; if the latter, he received the full benefit of the courses in mathematics and ignored the humanities. Similarly, at the Lycée Napoléon, those who wished to try for admission to the Ecole polytechnique or to enter the army took a two-year intensive course in mathematics. Finally, so that there could be no doubt as to the close link between the study of the sciences and the military requirements of the Empire, in 1812 the better students in mathematics were requisitioned by the Minister of War and sent straight from the classroom to the battlefield.

The pursuit of a scientific education was, therefore, tantamount to enlisting, and to many parents the lure of the sciences must have been more than counterbalanced by the prospect of active military service. To the bourgeoisie, who were the main support of the *lycées*, a civil career must have seemed to offer a more secure, stable and lucrative future for their sons.

. . . .

The history of the Ecole polytechnique under the Consulate and Empire is the story of the slow deterioration of this school. Founded in September 1794 through the efforts of Lamblardie, Monge, and Prieur (de la Côte-d'Or) as the École centrale des travaux publics, this institution had at its inception a purely practical function.

War has provided the French Republic with the happy opportunity of developing all the power of the arts. The fabrication of arms, of saltpeter and powder; the extraction of copper from bells; the use of balloons for observation posts for the armies; the establishment of telegraphs . . . the multiplication and invention of new arts of defense; these are the factors which have led the Committee of Public Safety to recognize the importance of the geometrical and physical sciences and the necessity of harvesting their fruits.

The requirements of defense and a vigorous prosecution of the war that assailed France on all frontiers determined the curriculum. Emphasis was placed upon the study of mathematics, necessary for the engineering profession, and the courses in this subject included calculus, mechanics, hydrostatics, and hydrodynamics. From this theoretical base, the student was led to the practical applications of mathematical principles to map-making, fortification, civil and military architecture, and surveying. The study of descriptive geometry was similarly combined with practical exercises in masonry, carpentry, and the drawing of plans. The course in chemistry was designed simply to introduce the student to the various materials of construction, special courses being given in the properties of saline substances, organic material, and minerals, "the most important materials used in public works."

When the immediate threat of invasion and successful counterrevolution had receded, however, the school was reorganized along more liberal lines. Instead of being a school solely for the creation of military engineers, it was transformed into a general school of advanced science in order "to instruct those who wish to cultivate the arts and sciences for their own use, or to use their scientific knowledge in civil pursuits." The effect on the curriculum was to broaden it so that the pure sciences occupied a predominant place. The most striking change was in the study of chemistry. The three courses devoted to the study of the chemical properties of materials of construction were replaced by courses in chemical theory, laboratory practice, and chemistry applied to the technical arts. In physics, more attention was paid to the theoretical foundations, and the sections of the course devoted to astronomy, optics, and acoustics were greatly expanded. Mathematics became the cornerstone of the entire course of study, and complete courses in analytical geometry, differential and integral calculus were required. Such a curriculum served both those intending to enter the public services and those who desired to remain in civilian life and use their scientific training as they saw fit. In 1799, immediately after the coup d'état of *brumaire* which brought Napoleon to power, fifty graduating students of the Ecole polytechnique entered the military services, while twenty-seven remained civilians.

At the time of Napoleon's rise to power, the Ecole polytechnique was the foremost school of science in the world. From its classrooms came not only the artillery officers and military engineers so necessary to the victorious advance of the armies of the Republic, but also teachers, manufacturers, and scientists. Under Napoleon the aim and purpose of this school was slowly restricted until, by the time of the collapse of the Empire, it produced only officers for the armed forces.

All the signs at the time of Bonaparte's coup d'état indicated a prosperous future for the Ecole polytechnique. Monge and Berthollet, both professors at this school, had accompanied Napoleon on the Egyptian campaign and were personal friends of the First Consul; Fourcroy, one of the professors of chemistry at the Ecole polytechnique, was chosen by Napoleon to be his director of public education, and Laplace became the first minister of the Interior under the new regime. The relationship between the faculty and the First Consul was seemingly most cordial.

Barely a month after 18 *brumaire,* however, the first step was taken in the process of militarization. The law of 25 *frimaire an* VIII (26 December 1799) abolished the freedom to choose their careers which the students had hitherto enjoyed. Henceforth, every student accepted by the Ecole polytechnique had to select the branch of the public service in which he wished to serve upon graduation. Although the student was still allowed to make this choice, the law denied the principle established by the reorganization of the school in 1795. No longer was the Ecole polytechnique to be a source of benefits for all aspects of French society; instead, it was to be restricted to the provision of replacements for the public services. Since the law made no changes in the curriculum it aroused little opposition, but it clearly foreshadowed the "reforms" to come.

In 1804, another reorganization was accomplished, which left little doubt as to the function which the Emperor believed the Ecole polytechnique should perform. By the decree of 27 *messidor an* XII (16 July 1804) the school was transformed into a military academy. The students were formed into companies under the command of sergeants and corporals chosen from their own ranks. The former policy of allowing the students to room and board with the residents of Paris was abolished and a barracks system instituted. Arms and uniforms were issued and the students marched from their barracks to their classes in military dress and formation.

The curriculum was also changed to conform with the new character of the school. Emphasis was shifted from the sciences to those studies of special importance in war.

The students will be more particularly occupied with the study of design; they will not be admitted to the school until they show competence in drawing; they will be exercised in drawing architectural plans, plans of machines, fortifications, and maps in perspective and in geometrical lay-out.

The administration of the school was attributed to a military governor, and the Conseil de l'Ecole polytechnique (composed of the professors and members of the Institute), which had built the school up to its pre-eminent position, was suppressed.

From 1804 until the end of the Empire, the military character of the school became more and more obtrusive. In 1805, at the suggestion of Napoleon, the courses in advanced mathematics and chemistry were shortened in order that more time could be devoted to the courses in fortification and military science. After 1806, the Emperor felt free to send detachments of special students to the school for an accelerated and narrow education which would equip them for posts in the line but which was far inferior to that which had been offered in 1798. In 1809, the regular students had lost the last vestige of their freedom of choice of a profession. They still indicated the public service in which they wished to serve, but they were at the call of the Minister of War, who placed them where they were needed.

This policy of using the Ecole polytechnique as a private reserve from which technically trained men could be drawn for service in the military branches had an inevitable effect upon the instruction in the sciences. All teaching was subordinated to the necessities of the art of war. The courses were simplified and "directed towards their practical aspects." Even in the courses in mathematics, so necessary for the artillery officer and military engineer, this "simplification" took place.

> The Council has removed the higher aspects of the courses in analytical geometry and mechanics since they were of no use in the services and consumed, as simple mental exercises, time which the students needed for practical studies.

No longer did they use the method of analysis in which basic principles were explained and then all particular cases analyzed and solved by means of these principles. Instead, specific problems were stated and solutions were given in terms of formulae applicable to definite situations. This new method was a denial of the spirit which had characterized the Ecole polytechnique of the Directory. But instruction in the fundamental theories of the sciences took too much time; it was more efficient to teach the application of formulae, committed to memory, to specific situations than to try to explain why certain solutions were correct and others incorrect. Practical knowledge, not understanding, was the paramount consideration.

> [The teachers] will show the students all the applications of theory which do not require too complicated calculations or abstract notions not immediately verifiable by experience.

Mathematics, physics, and chemistry, which had occupied the key positions in the curriculum before *brumaire,* were now relegated to secondary roles. Topography, map-making, the accurate sketching of enemy fortifications and the designing of fortresses—these were the matters which were practical and necessary for the student to know.

Thus, in the years from 1798 to 1815, the Ecole polytechnique underwent a profound transformation. From a school devoted to the teaching and dissemination of the physical and mathematical sciences, in all their development, it became a school for the teaching of the art of war. From a school run by the professors, all of whom sensed that abstract and sometimes romantic ideal of the man of science, whose greatest joy is the extension of knowledge, it became a school ruled by a military governor whose main function was to insure that the gaps in the ranks of the military forces were filled by men who could successfully cope with the practical problems of warfare.

Throughout his reign and his years of exile on St. Helena, Napoleon tried his utmost to prove to the French and the world at large that he was a true patron of science. His beautifully staged presentations of medals to Volta and Davy; the éclat with which he presided, when possible, at the Institute; his friendships with the leading scientists of the day; the reports commissioned by him and written by Cuvier and Delambre on the progress of science since 1789, and his own statements were, at least partially, directed towards this end. Yet when viewed against the provisions for the teaching of science in the Napoleonic schools, these attempts seem to be more in the nature of propaganda than the honest expressions of a deeply felt respect for science. The scientific institutions which the Revolution and Directory had created, to be sure, with imperfections, were either suppressed or radically changed by the Emperor until they fitted into his concept of a military state. Science, in this state, occupied a position defined almost entirely in a narrow, utilitarian manner, and any attempt to institutionalize a concept of science which went beyond this utilitarianism was immediately thwarted.

The character of the Napoleonic reforms, especially of secondary education, also was to influence the future development of French science. By returning, at least partially, to the practices of the *Ancien Régime* and by repudiating the experiments of the Directory, Napoleon isolated the Revolution. The result was to create an aura of subversion which surrounded the institutions created by the Republic. During the Restoration and the July Monarchy, advocacy of the Enlightenment, with its almost total reliance on science as the instrument for achieving the Utopia of which the *philosophes* dreamed, became the major political heresy. The educational efforts of the Directory, which had applied these concepts to the system of public instruction, were likewise objects of scorn. It is significant that the major efforts for the reform of the Université Impériale after the Restoration did not come from the advocates of more and better scientific training, but from the Church which desired to re-establish its educational monopoly. Saint-Simon and Comte preserved the tradition of the *Idéologues,* but their influence was not felt in the realm of education until the Second Empire and the Third Republic. Science in a vague and almost intangible way was somehow politically disreputable and revolutionary. As long as it remained within the limits imposed by Napoleon, it was respected; when, as with Saint-Simon and Comte, science was used as an argument for the reform of the state, it was relegated to the lunatic fringe and derided.

The effect of the predominance given belles-lettres in the Napoleonic educational system is an even more vague and difficult one to analyze. Coming as it did at the beginning of the Romantic revolt, it is probable that the accent on literature and the potentially romantic past buttressed this movement and tended to complete the metamorphosis of values begun with the Revolution itself. In the eighteenth century, the scientist had had the key to truth, and the savants of the *Ancien Régime* had found that their learning gave them an entrée to the highest levels of society. The experience of the Revolution, however, had shattered the ideal which had so captivated the Enlightenment, and the Empire had reduced the scientist from the rank of prophet to that of a useful and necessary technician. After the Restoration, the prophets of the new age were to be found, not among the ranks of the scientists, but among those of the literary figures of the period. An Arago was respected but a Hugo was idolized. To the youth of this period, the excitement of "la vie de bohême" and the social prestige of the successful poet and serious writer [4] must have been important arguments in favor of a literary career. The education of the intelligent student, by emphasizing the humanities, probably reinforced these leanings, while the study of the sciences was relegated to an inferior position. The example of Claude Bernard arriving in Paris with the manuscript of a tragedy in his pocket and turning to science only after his literary ambitions had been crushed comes immediately to mind. And surely there must have been many others who were like him but who preferred to remain second- and third-rate scriveners rather than to begin anew their education in the sciences.

Perhaps the most important effect of the Napoleonic reforms of education as far as the future of French science was concerned, was the close link forged during the Empire between science and the military. To the bourgeoisie, who were potentially the most receptive audience, science meant not an instrument for the increasing of production in manufactures and agriculture but a military career which, while glorious, might also be short. By making science the exclusive property of the armed forces, the Empire also deprived French industry and agriculture of one of their most important tools at a crucial period in their development. By the time this monopoly was broken, the old social values had been re-established, and the bourgeoisie looked upward to the aristocracy, not downward to the *atelier*. The chance to create a highly trained and technically competent middle-class had gone by, and France soon saw her industries surpassed, not only by those of England, which had always held the lead, but by those of Belgium and Germany, where it was not considered dishonorable to deal in the "mechanical arts."

The effects of the Napoleonic educational reforms have entered into the very fabric of French life. The basic system was preserved until the Third Republic, and even then the various changes made were relatively superficial. Napoleon, of course, cannot be charged with the change of values that reduced the importance of science in the everyday life of France. But the reforms he accomplished did serve to accelerate this change, and the debasement of the teaching of science was to help in creating a France in which the great gap between the pure scientist and the skilled worker has never been adequately filled.[5]

NOTES

[1] For a detailed study of the philosophy behind the educational system of the Directory and the success of this philosophy when put into practice, see L. P. Williams, "Science, Education and the French Revolution," *Isis*, 1953, 44:311–330.

[2] Arch. Nat., F17 1339, Mémoire sur l'instruction publique addressée aux Consuls.

[3] Cited in G. Dupont-Ferrier, *Du Collège de Clermont au Lycée Louis-le-Grand* (2 vols., Paris, 1922), pp. 2, 238.

[4] No better example of this difference in values which post-Imperial society placed on science and literature can be found than in Honoré de Balzac's trilogy. *Les illusions perdues,* published separately as *Les deux poètes* (Paris, 1837), *Un grand homme de province* (Paris, 1839), and *Les souffrances d'un inventeur* (Paris, 1843). Lucien de Rubempré, one of the protagonists, is a poet and writer who uses his skills to rise in the social world. He is wined and dined in Angoulême and then sets out for Paris, where he is given an immediate entrée to society. The other protagonist, David Séchard, is a printer's son who spends his life trying to discover a new process for the manufacture of paper. Balzac contrasts David's virtue with Lucien's vices, but there is no doubt as to which one leads the more exciting and socially brilliant life.

[5] The problem is still one which plagues France. See Benjamin Fine's report on the new plans for the reform of French education in the *New York Times,* Sunday, 21 August 1955, section 4, p. 9.

DARWINISM, RELIGION, AND MORALITY: POLITICS AND SOCIETY *

Gertrude Himmelfarb

In the following selection Gertrude Himmelfarb argues that political beliefs and morality have no source in science. Instead they spring from man's rationalizations or from religion; but such is the authority of science in our world that we seek its sanction for our most cherished convictions.

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* From *Darwin and the Darwinian Revolution* by Gertude Himmelfarb. Copyright © 1959, 1962 by Gertrude Himmelfarb Kristol. Reprinted by permission of Doubleday & Company, Inc. See Michael Banton, ed., *Darwinism and the Study of Society,* London, 1961; Loren Eisley, *Darwin's Century,* New York, 1958; Charles Gillispie, *Genesis and Geology,* Cambridge (Mass.), 1951; Richard Hofstadter, *Social Darwinism in American Thought,* 2nd edition, Boston, 1955; Julian Huxley, *Evolutionary Ethics,* Oxford, 1943; William Irvine, *Apes, Angels, and Victorians,* New York, 1955; and Geoffrey West, *Charles Darwin,* London, 1937. [Editor's note.]

Ideas have a radiation and development, an ancestry and posterity of their own, in which men play the part of godfathers and godmothers more than that of legitimate parents. In this dictum of Lord Acton may be seen the relationship between Darwin and Darwinism, between the theory of natural selection and the theories of religion, morality, society, and politics presumably derived from that theory.[1] Of the ancestry of his ideas or the climate of opinion in which they were nurtured, Darwin had little real knowledge or appreciation; of their posterity or the climate which they created, he had, necessarily, even less. It has already been observed how much narrower in extension and more specific in intention were his theories than either the background from which they emerged or the response which they evoked; the image is of an hourglass, with Darwin comprising the narrow waist. . . .

The religious managed to find in Darwinism a variety of consolations and virtues not dreamed of even in natural theology. One distinguished botanist bewildered Darwin by declaring himself a convert on the grounds that the theory finally made intelligible the birth of Christ and redemption by grace. A clergyman was converted on the grounds that it opened up new and more glorious prospects for immortality. And theologians declared themselves ready to give up the old doctrine of "the fall" in favor of the happier idea of a gradual and unceasing progress to a higher physical and spiritual state.

It was not even necessary to interpret Darwinism teleologically in order to find religious meaning in it. Some Calvinists gloried in it precisely because it exalted chance, not design. It was this that confirmed their faith in special providence, in the arbitrary election of the chosen, and in the spontaneous, unpredictable, and often tragic nature of the universe. A prominent American theologian, holder of the chair of "The Harmony of Science and Revelation," suggested that Darwinism was to natural science as Calvinism was to theology: a foe to sentimentalism and optimism, a check on the reign of law and the trust in reason.

In the Catholic Church, Darwinism had a history and literature of its own. As has already been observed, Catholics were, in some respects, better situated than Protestants to accept Darwinism. Depending rather on the authority of the Church than on Scripture, they were not bound by the literal Biblical texts; ecclesiastical authority could and did interpret the Biblical account of creation as it saw fit. It was, indeed, the purpose of Newman's theory of development, which anticipated the *Origin* by over a decade, to provide a rationale for the evolution and progressive re-interpretation of dogma. Liberal Catholics, wanting to exploit this Scriptural freedom, and at the same time wanting to endear themselves to other liberals, besought the Church not to intervene in scientific quarrels. On the eve of the publication of the *Origin,* Newman himself urged this course upon the hierarchy, not only on the plea that Catholics deserved to be spared any addition to the heavy load of controversy which they already bore, but also because, by copying "the divine wisdom in not making formally binding the old accepted cosmology," they would demonstrate to the world the "divinity of their religion." [2]

The Papacy, however, assured both of its divinity and of a measure of wisdom larger than that credited it by Newman, thought that aggression rather than discretion was called for. In 1864 Pius IX issued the "Syllabus of Errors" condemning "progress, liberalism and modern civilization." Although this was commonly understood to include Darwinism, many Catholics, taking advantage of the absence of any formal prescription (neither the *Origin* nor the *Descent* ever joined Erasmus Darwin's *Zoonomia* on the Index), continued to speculate freely with evolutionary ideas. Some went further than St. George Mivart, and perhaps even further than Darwin himself. At the centenary celebrations of Darwin's birth, Canon Dorlodot, representing the University of Louvain, praised him for revealing a creation grander and worthier of God than had before been suspected. Later he wrote a book on Darwinism, in which he declared that both the principles of Catholic exegesis and the teachings of the Church fathers made "eminently probable the theory which derives all living things from one or a few very simple types of organisms." Although he specifically left out of consideration the problem of the origin of man, he more than made up for this by his attitude toward the origin of life. Of Darwin's suggestion that a special intervention of God still seemed necessary to account for the creation of life, Dorlodot cavalierly remarked that this was probably a legitimate hypothesis—"at least for the time being." [3]

A century after the publication of the *Origin,* Catholics were able to assert with impunity the entire teachings of Darwin, even on the development of man, provided only that they did not tamper with the divine origin of the soul. (Since Darwin did not speak of a "soul," this was no great hardship.) The encyclical "Humani Generis," published in 1950, condemned the idea that evolution could account for the origin of all things, on the grounds that such an extension of the theory was conducive to a variety of heresies: monism, pantheism, dialectical materialism, idealism, immanentism, pragmatism, and existentialism—in short, all those "false opinions," as the subtitle put it, "which threaten to sap the foundation of Christian teaching." But it conceded that a more modest theory of evolution, concerning itself only with the physical development of the human body, would avoid this litany of errors and be a legitimate subject of research. Most Catholic evolutionists professed to be well satisfied with this pronouncement. An article in the Jesuit journal, the *Month,* said that while "macro-evolution does not show up too well" on the evidence, it was nevertheless preferable to "special creation," the omnipotence of God being best revealed in the laws of nature. The only qualification the Catholic need make was the belief that "God intended, from all eternity, to create Man to put him in this world as the crown of this particular order of creation, and that He took those means which He saw to be most suitable for the purpose." [4]

When Henry Adams wrote that "unbroken Evolution under uniform conditions pleased everyone—except curates and bishops; it was the very best substitute for religion; a safe, conservative, practical, thoroughly Common-Law deity," [5] he had underestimated its appeal. The most respectable curates and bishops were even then succumbing to its charms.

The basic religious quarrel provoked by the *Origin* was not between the theists who rejected it and the atheists who favored it, as has been thought, but rather between the reconcilers and the irreconcilables, those who believed that *Origin* was compatible with Christianity and those who thought that it was not. The irreconcilables of both parties—the one *rejecting* Darwinism because it demeaned religion, the other *embracing* Darwinism because it demeaned religion—were as contemptuous of the efforts of the reconcilers as they were hostile to each other. Huxley, engaged in debate with the elusive Gladstone, finally protested: "There must be some position from which the reconcilers of science and Genesis will not retreat." [6] The god of the reconcilers too often resembled that of Coleridge: "a something-nothing-everything which does all of which we know." [7] Agnostics and believers alike objected that such a god "who is the final reason of everything is the scientific explanation of nothing." [8] They dismissed as pat and meaningless the clever paradoxes: "providence without a god," [9] "religion without revelation," [10] a god who was identical with "space-filling matter." [11]

If the agnostics were aggrieved at the thought of a fruitless victory in which Darwinism was assimilated into the old religious categories, many religious men were dismayed by a defeat that might turn out to be even more disastrous than had at first appeared. To the religious irreconcilables, Darwinism threatened to suck in a multitude of well-intentioned people on the pretense of offering them a respectable compromise. But the compromise, they felt, was a sham, a façade behind which lurked skepticism and atheism. What the reconcilers saw as an aloof and noble god who did not stoop to intrude in the practical administration of his realm, the irreconcilables saw as an impoverished and impotent monarch, a ceremonial figurehead. Thus Agassiz complained of the "repulsive poverty" of the god of the evolutionists: "The resources of the Deity," he protested, "cannot be so meagre, that in order to create a human being endowed with reason, he must change a monkey into a man." [12] R. H. Hutton said that what scandalized many was the thought that God should be presumed to work in the tentative and negative fashion implied by Darwinism: "They ask how an omniscient mind which knows precisely what is wanted, can set Nature *groping* her way forward as if she were blind, to find the path of least resistance." [13]

What the religious feared was that this new god, who bore so attenuated a resemblance to the old, would become more and more attenuated until little remained to identify him as God at all. The irreconcilables, it would seem, took more seriously than their opponents the inevitability and pervasiveness of the evolutionary process. They saw that the new evolutionary theology was itself subject to the laws of evolution and that it would necessarily evolve toward an expanding Darwinism and a diminishing religion. Hutton was only one of many, in Darwin's own time, to point to the danger of reducing God to the status of a logical postulate, and impersonal First Cause, far removed from the concrete facts and processes of nature as men experience them:

The people who believe today that God has made so fast the laws of His physical universe, that it is in many directions utterly impenetrable to moral and spiritual influences, will believe tomorrow that the physical universe subsists by its own inherent laws, and that God, even if He dwells within it, cannot do with it what He would, and will find out the next day, that God does not even dwell within it, but must, as M. Renan says, be "organised" by man, if we are to have a God at all.

The dispute about the religious significance of Darwinism was part of a long history of religious controversy. God was being "organised" by man long before the *Origin* appeared, and the hopes and fears that greeted Darwin's work were echoes of earlier exultations and laments. It is neither to deny nor denigrate the sincerity of the despair felt by so many upon reading the *Origin* that one recalls similar outbursts a century and more before. It was in 1736 that Bishop Butler complained: "It is come, I know not how, to be taken for granted, by many persons, that Christianity is not so much a subject of inquiry; but that it is now at length, discovered to be fictitious." . . .

What the *Origin* did was to focus and stimulate the religious and nihilist passions of men. Dramatically and urgently, it confronted them with a situation that could no longer be evaded, a situation brought about not by any one scientific discovery, nor even by science as a whole, but by an antecedent condition of religious and philosophical turmoil. The *Origin* was not so much the cause as the occasion of the upsurge of these passions.

As men were provoked to take up new or exaggerated religious positions, so they were inspired to rethink the philosophical basis of morality. Darwin did this in a primitive fashion in the *Descent,* but long before then, before even the *Origin,* Herbert Spencer had set down the basic principles of evolutionary ethics. It was Spencer's belief that by basing morality on evolution, he had created not merely a philosophy of ethics but a science of ethics. Moral conduct was defined as that which contributed to man's better adaptation and to his higher evolution. Since personal happiness was also the result of a satisfactory adaptation, morality and happiness were essentially one. Thus utilitarianism was amalgamated with evolutionism, the individual was reconciled with society, and hedonism became altruism under a different guise. The perfect moral man, "the completely adapted man in the completely evolved society," was one in whom there was a "correspondence between all the promptings of his nature and all the requirements of his life as carried on in society." Essentially the same argument appeared later in Leslie Stephen's *Science of Ethics.* Again what was sought was the rooting of ethics in science; like Spencer, Stephen was concerned to provide a sanction for morality that was not dependent upon the discredited dogmas of religion, particularly of immortality. And again the test of individual conduct was found in the welfare of society, and the warrant of individual happiness in social utility. Morality, happiness, and the evolutionary process were assumed to be different aspects of the same thing.

There were many, and not only among the religious orthodox, who found this multiple identity both superficial and arbitrary. Henry Sidgwick warned Stephen that evolutionism and utilitarianism were not so easily reconciled, that the evolutionary movement of society did not necessarily promote the greatest happiness of the greatest number, still less the greatest happiness of any one individual. And many others, like Morley, were distressed by the deterministic implication of Darwinism. If morality is determined by the impersonal processes of nature, "what becomes of man's voluntary agency"? What is moral behavior if not a voluntary act of will? What have science and nature to do with ethics? Even if Darwinism could explain the development of the moral sense, which was doubtful enough, this did not authorize it to prescribe any particular moral code. The ethical Darwinists, their critics said, had been guilty of the ancient fallacy of confusing description with prescription, of making facts—and dubious facts at that—do service for values.

What made matters worse was the apparently immoral character of nature revealed by evolution itself, hardly qualifying it to set itself up as a preceptor. No one any longer shared Paley's faith in the benevolence of nature: "It is a happy world after all. The air, the earth, the water teem with delighted existence. In a spring noon, or a summer evening, on whichever side I turn my eyes, myriads of happy beings crowd upon my view." When Paley rhapsodized over the thoughtfulness of a God who devised that clever structure in the throat to prevent choking—"consider a city-feast, what manducation, what deglutition, and yet not one Alderman choked in a century"—the reader was now apt to reflect that this was to look at the matter too exclusively from the point of view of the alderman, and not enough from that of the sacrificial sheep or lobster.

Men did not need Darwin to convince them that nature was not a reliable guide to the conscience. Matthew Arnold had given them fair warning:

> Nature is cruel, man is sick of blood;
> . . .
> Nature is fickle, man hath need of rest.
> . . .
> Man must begin, how this, where Nature ends;
> Nature and man can never be fast friends.

And Swinburne learned the same lesson, not from Darwin but from that "modern pagan philosopher," the Marquis de Sade:

> Nature averse to crime? I tell you, nature lives and breathes by it; hungers at all her pores for bloodshed, aches in all her nerves for the help of sin, yearns with all her heart for the furtherance of cruelty. . . . Unnatural is it? Good friend, it is by the criminal things and deeds unnatural that nature works and moves and has her being. . . . If we would be at one with nature, let us continually do evil with all our might.

But although the theme of nature's cruelty is an ancient one, and texts to that effect readily accessible, it was Darwin who was generally taken as the authority. What others had vaguely sensed, he was thought to have proved: cruelty was not only a fact of nature; it was the governing force of nature, the motivating power of life. . . .

Darwinism, Politics, and Society

Even those who are entirely convinced of the validity of Darwin's scientific doctrines may be wary of their extension to political or social theory. They may feel about "social Darwinists" as Newman felt about secularists: "They persuade the world of what is false by urging upon it what is true." More than most theories, Darwinism lent itself to such stratagems of persuasion, enjoying not only the prestige and authority attached to science but also the faculty of being readily translated into social terms. That this translation was necessarily rather free and loose was an added advantage, since it gave license to a variety of social gospels. . . .

There were deductions that might be drawn from the *Origin* in respect of race, and on the eve of the Civil War it was inevitable that they would be drawn. The only difficulty was that they could be made to favor either side. The most obvious deduction was the anti-racist one: the theory of evolution, by denying the separateness of varieties and species also denied the separateness and thus the intrinsic inferiority or superiority of races. Slavery was therefore not an inviolable condition of nature but an ephemeral condition of history; by nature all men were brothers. When Asa Gray first read the *Origin,* he could not help wincing at the idea of being made kin to the Hottentot and Negro; a Northerner and abolitionist, however, he managed to suppress such unworthy thoughts. Others, starting from the unshakable conviction that Negroes and whites could not have come from a common stock, found this a decisive argument against the *Origin*. (It was also an argument against the Biblical theory of creation, but few men pursued the matter so far.) In strict logic, there is no reason why this reading of the *Origin* should have had these consequences: why an evolutionist could not have argued that history, if not nature, had made of the Negro an inferior race fit only for slavery; while the anti-evolutionist argued that whatever the facts of nature, morality and political expediency dictated a policy of abolition. Unfortunately, few men had the firmness of mind to resist the authority of nature and science, and to take their stand on purely moral or political grounds.

It was not, however, necessary to confute the *Origin* in order to justify the South. It was only necessary to re-interpret it. For there were features of Darwin's theory that could easily give comfort to the proponents of slavery and racism. Although Darwin derived all races, like all species, from a single historic ancestor, he by no means denied the reality of separate races and species in the present. He did not dissolve all species into an undistinguished mass of individuals; he did not even suggest, as anti-racists theorists often do, that individuals constitute a spectrum in which each differs from his neighbor so slightly that only artificially, statistically, can varieties, races, or species be distinguished. Indeed, the purpose of his doctrine was precisely to account for the reality of species, to explain not only how species evolved but also how they became stabilized and fixed in form, sometimes for very long periods (sometimes—and it was one of Darwin's main tasks to account for this—for all of recorded history). Nor did he deny that under certain conditions it was desirable to maintain, as far as possible, the purity of races. The *Origin* did declare that crosses between varieties tended to increase the number, size, and vigor of the offspring. But this was true only in special cases: where, for example, the crossed varieties had previously been exposed to fluctuating conditions and thus were especially hardy. Otherwise, such a cross might prove fatal to both varieties.

It was this argument against the crossing of races that first impressed itself upon some of the readers of the *Origin*. One month after publication, on the occasion of John Brown's raid at Harpers Ferry, the *Times* gave warning that the abolitionists would turn the population of the South into a "mixed race." The lesson of modern times, it said, was that such a mixture of races "tends not to the elevation of the black, but to the degradation of the white man." Reading this, a secretary at the American legation in London observed: "This is bold doctrine for an English journal and is one of the results of reflection on mixed races, aided by light from Mr. Darwin's book, and his theory of 'Natural Selection.' "

The subtitle of the *Origin* also made a convenient motto for racists: "The Preservation of Favoured Races in the Struggle for Life." Darwin, of course, took "races" to mean varieties or species; but it was no violation of his meaning to extend it to human races, these being as much subject to the struggle for existence and survival of the fittest as plant and animal varieties. Darwin himself, in spite of his aversion to slavery, was not averse to the idea that some races were more fit than others, and that this fitness was demonstrated in human history:

> I could show fight on natural selection having done and doing more for the progress of civilization than you seem inclined to admit. Remember what risk the nations of Europe ran, not so many centuries ago of being overwhelmed by the Turks, and how ridiculous such an idea now is! The more civilized so-called Caucasian races have beaten the Turkish hollow in the struggle for existence. Looking to the world at no very distant date, what an endless number of the lower races will have been eliminated by the higher civilized races throughout the world.

From the "preservation of favoured races in the struggle for life," it was a short step to the preservation of favored individuals, classes, or nations—and from their preservation to their glorification. Social Darwinism has often been understood in this sense: as a philosophy exalting competition, power, and violence over convention, ethics, and religion. Thus it has become a portmanteau of nationalism, imperialism, militarism, and dictatorship, of the cults of the hero, the superman, and the master race. The hero or superman, most recently translated as *Führer,* is assumed to be the epitome of the fittest, the best specimen of his breed, the natural ruler who exercises his rule by right of might. As he is the instrument of providence to lead his nation to victory, so the nation is the instrument that will raise civilization to a more sublime state. And as he made his way by struggle and force, so the nation must make its way in the world by war and conquest. A German general has given the classical expression to this glorification of struggle:

> War is not merely a necessary element in the life of nations but an indispensable factor of culture, in which a truly civilized nation finds the highest expression of strength and vitality. . . . War gives a biologically

just decision, since its decisions rest on the very nature of things. . . . It is not only a biological law, but a moral obligation, and, as such, an indispensable factor in civilization.

For the general, it was the needs of war that came first, the imperialist adventures and nationalist experiments that followed. For others it was the reverse: the imperialist and nationalist aspirations brought war and militarism in their wake. There were even some who would have liked the virtues of war without the onus of militarism or nationalism; this was social Darwinism in its purest, most disinterested form. Sir Arthur Keith, the anthropologist, evolutionist, and biographer of Darwin, confessed that although he personally liked the thought of peace, he feared the results of such an experiment. At the end of five centuries of peace, he predicted, the world would look like "an orchard that has not known the pruning hook for many an autumn and has rioted in unchecked overgrowth for endless years." He was no champion of war, he protested, but he could not conceive of any substitute that would serve as well "for the real health of humanity and the building of stronger races."

Recent expressions of this philosophy, such as *Mein Kampf*, are, unhappily, too familiar to require exposition here. And it is by an obvious process of analogy and deduction that they are said to derive from Darwinism. Nietzsche predicted that this would be the consequence if the Darwinian theory gained general acceptance:

If the doctrines of sovereign Becoming, of the liquidity of all . . . species, of the lack of any cardinal distinction between man and animal—doctrines which I consider true but deadly—are hurled into the people for another generation . . . then nobody should be surprised when . . . brotherhoods with the aim of robbery and exploitation of the non-brothers . . . will appear on the arena of the future.

Perhaps the most common understanding of social Darwinism is as a philosophy of extreme individualism, of laissez-faire in economics and government. If this seems far removed from the nationalism and authoritarianism that also go by the name of "social Darwinism," it has no less right to that title.

It was not only the theory itself—the struggle for existence and survival of the fittest—that suggested the idea of laissez-faire, but also the genesis of that theory. From Malthus to Darwin and back to a Malthusian Darwinism: the system seemed to be self-sufficient and self-confirming. The theory of natural selection, it is said, could only have originated in

England, because only laissez-faire England provided the atomistic, egoistic mentality necessary to its conception. Only there could Darwin have blandly assumed that the basic unit was the individual, the basic instinct self-interest, and the basic activity struggle. Spengler, describing the *Origin* as "the application of economics to biology," said that it reeked of the atmosphere of the English factory. Nietzsche was similarly repelled by it: "Over the whole of English Darwinism there hovers something of the suffocating air of ever-crowded England, something of the odour of humble people in need and in straits." And commentators since then, although as often as not without any Nietzschean or Spenglerian bias, have repeated the refrain; natural selection arose and throve in England because it was a perfect expression of Victorian "greed-philosophy," of the capitalist ethic and Manchester economics.

Social laissez-faire being an extension of economic laissez-faire, it was credited with the same Darwinian motives. In society, as in nature, there was presumed to be a "natural order" which, left alone, would insure the survival of the fittest. Any interference with that order, either to direct the organization of society or to protect special interests, would violate nature and enfeeble society. Darwin himself, bemoaning the future of humanity, once complained that "in our modern civilization, natural selection had no play, and the fittest did not survive." It did not take the *Origin* to persuade men of the evils of social reform, of interfering with the natural competitive order. Malthus was persuaded of this, at the same time that he deprecated the idea of evolution. A theory of evolution did help, however, although it did not have to be Darwin's. Almost a decade before the *Origin*, Spencer protested against those misguided reformers who would shield men from the full rigors of the struggle for existence:

> The well-being of existing humanity, and the unfolding of it into this ultimate perfection, are both secured by that same beneficent, though severe discipline, to which the animate creation at large is subject; a discipline which is pitiless in the working out of good; a felicity-pursuing law which never swerves for the avoidance of partial and temporary suffering. The poverty of the incapable, the distresses that come upon the imprudent, the starvation of the idle, and those shoulderings aside of the weak by the strong, which leave so many "in shallows and in miseries," are the decrees of a large far-seeing benevolence.

The leading American disciple of Spencer, William Graham Sumner, warned society that it faced the alternative of the survival of the fittest or the survival of the unfittest, the ill-conceived humanitarian efforts to alleviate poverty and preserve the weak having the effect of favoring the worst members of society and lowering the vitality of civilization. And John D. Rockefeller once regaled a Sunday-school audience with an account of how natural selection operated for the best interests of society as a whole. He compared the evolution of business with the evolution of a superior variety of rose: as the American Beauty could only have been produced "in the splendor and fragrance which bring cheer to its beholder," by sacrificing the buds which grow up around it, so the development of a large business is "merely a survival of the fittest . . . merely the working-out of a law of nature and a law of God."

Against this iron law of nature, there was no appeal. Certainly there was no appeal to such fictions as equality, justice, or natural rights. As there were no such principles in the jungle, so there were none in society. "There can be no rights against Nature except to get out of her whatever we can, which is only the fact of the struggle for existence stated over again." Society had to develop organically out of its own inner compulsions, rather than artificially out of the minds of reformers. There were no fixed species in nature and, in the same way, no ideal values in society. All was relative, historical, evolving. The only fixed point of reference was liberty, the freedom to evolve in whatever way nature chose, the freedom of the fit to survive and of the unfit to die.

What gave unity to these diverse and often contradictory interpretations of social Darwinism was the idea of struggle, the unrelenting war to which nature and mankind were eternally doomed. Yet it was possible to be diverted from the competitive struggle of life today to the vision of a non-competitive, pacific life in the future. Even Spencer held out hope that the struggle for existence, so essential to the present welfare of man and a necessary condition for his evolution, would eventually be outmoded in consequence of that very evolution. As mankind adapted itself to the changing conditions of life, a new human nature would develop. The military struggle would give way to the milder industrial one, and society would find itself encouraging the pacific, cooperative virtues in place of the militant, competitive ones. Finally there would emerge an ideal man, the epitome of perfection and happiness, in complete harmony with his environment and unaffected by struggle or competition. The American philosopher John Fiske, predicted the same happy issue, the evolutionary processes of selection and adaptation serving ultimately to bring about a condition in which the desires of each individual would be in "proximate equilibrium" with the desires of others and also with the means of satisfying them. When this happened, when selection and adaptation came to an end, and the ape and tiger in man were extinct, strife and sorrow would disappear, and the kingdom of this world would become the kingdom of Christ.

It was this comforting reading of Darwinism, achieved by a judicious divorce of present and future, that made it possible for yet another creed to enter the amalgam of social Darwinism. Nothing, at first sight, could seem more remote from each other than the doctrines of laissez-faire and socialism. Yet socialists, too, have claimed descent from Darwin, and with some right.

When Marx read the *Origin*, he enthusiastically declared it to be "a basis in natural science for the class struggle in history." And when a new edition of his *Capital* appeared, he presented Darwin with a copy, later offering to dedicate the English translation to him. While the dedication was refused on religious grounds, the gift of the book, which apparently remained unread, was politely acknowledged: "Though our studies have been so different, I believe that we both earnestly desire the extension of knowledge; and this, in the long run, is sure to add to the happiness of mankind." If Darwin had not the least idea of what Marx was up to or what they might have in common, Marx knew precisely what he valued in Darwin. Recommending the *Origin* to Lassalle, he explained that "despite all deficiencies not only is the death-blow dealt here for the first time to teleology in the natural sciences, but their rational meaning is empirically examined." The other reason for his interest in the *Origin* emerged in the *Capital*, where he complained of the abstract materialism of most natural science, "a materialism that excludes history and its process." It was his hope that by focusing attention on change and development, the *Origin* would destroy both the old-fashioned supernaturalism and the equally old-fashioned materialism.

Yet there were obvious "deficiencies" in the *Origin*, from the point of view of Marxism, which even Marx did not fully appreciate. For the socialist, the struggle was primarily between classes, with "solidarity" prevailing within each class. For Darwin the basic struggle took place within each species (the species being the counterpart to class). It was here, where Spencer and Marx diverged, that Darwinism may be said to favor Spencer. Another point of disagreement was Marx's assumption that the struggle for existence would be suspended or transcended to permit the emergence of the classless society. Here Marx and Spencer were at one, agreeing that the struggle would eventually become obsolete through the dialectic of change and adaptation. The struggle for existence that Darwin took to be a permanent condition of animal life, Marx saw as a condition only of particular epochs in human history. One such epoch was the bourgeois one, where it might be fittingly said that the social organization was that of the animals. Recalling Hegel's description of bourgeois society as a *geistiges Tierreich,* he and Engels amused themselves with the thought that what English liberals took to be the greatest social achievement of their country should have been revealed to be the natural state of the jungle.

A more serious discrepancy between Darwinism and Marxism was expressed in Marx's contempt for "the crude English method of development." Between evolution and revolution there would seem to be no possible accord. Yet even here Marxists, intent upon retaining the authority of Darwinism, found ground for reconciliation. Plekhanov, defending Marxism against those simple-minded souls who thought that the doctrine of evolution meant *natura non facit saltus* and that revolution and evolution were therefore mutually exclusive, quoted Hegel to show how the dialectic resolved this antinomy, as it did so many others. The relationship between evolution and revolution was identical with that between quantity and quality; as imperceptible increases of quantity could produce a sudden transformation of quality, so the imperceptible movement of evolution could, at the critical historical moment, erupt into revolution. Later Marxists found a more plausible way out of the difficulty in the concept of mutations, which seemed to them to re-introduce those leaps in nature that were analogous to revolutions in history.

Even without these later emendations, however, there is an important sense in which Marx and Darwin alike were evolutionists. There was truth in Engels' eulogy on Marx: "Just as Darwin discovered the law of evolution in organic nature, so Marx discovered the law of evolution in human history." What they both celebrated was the internal rhythm and course of life, the one the life of nature, the other of society, that proceeded by fixed laws, undistracted by the will of God or men. There were no catastrophes in history as there were none in nature. There were no inexplicable acts, no violations of the natural order. God was as powerless as individual men to interfere with the internal, self-adjusting dialectic of change and development.

As their philosophical intent was similar, so was their practical effect. Against all those, socialists and others, who thought that men were moved by a basic harmony of interests, and that history advanced by making that harmony conscious and effective, Darwin and Marx insisted upon the basic fact of struggle and upon progress as its result. It was on this ground that Marxism had a legitimate claim to the title of "social Darwinism." And it was for this reason that some socialists, to Engels' horror, joined together Darwin, Spencer, and Marx as the trinity that would bring salvation to mankind.

While the "scientific socialists" sought to amalgamate Darwinism and Marxism into one irresistible system, other socialists hastened to dissociate themselves from the odious ideas of the struggle for existence and the survival of the fittest. Not struggle but cooperation was the spirit in which these socialists conceived their ideal—and not only their ideal but their means as well. They were happy to endorse Darwin's statement: "What a foolish idea seems to prevail in Germany on the connection between Socialism and Evolution, through Natural Selection."

Natural selection, dubious enough in nature, seemed to them still more dubious in society. What, they asked, is the significance of such concepts as struggle for existence and survival of the fittest in a complex civilization where "existence" and "fittest" are not physiologically or biologically determined, but only socially determined? If society chooses to favor the rich, the well-born, or the beautiful, what is there about them to qualify them as the fittest? And what is there about the struggle for such values as these to make men submit to it as the right and proper mode of social conduct? As William James observed: "The entire modern deification of survival *per se*, survival returning to itself, survival naked and abstract, with the denial of any substantive excellence in *what* survives, except the capacity for more survival still, is surely the strangest intellectual stopping place ever proposed by one man to another."

. . . .

In the spectrum of opinion that went under the name of social Darwinism almost every variety of belief was included. In Germany it was represented chiefly by democrats and socialists; in England by conservatives. It was appealed to by nationalists as an argument for a strong state, and by the proponents of laissez-faire as an argument for a weak state. It was condemned by some as an aristocratic doctrine designed to glorify power and greatness, and by others, like Nietzsche, as a middle-class doctrine appealing to the mediocre and submissive. Some socialists saw in it the scientific validation of their doctrine; others the negation of their moral and spiritual hopes. Militarists found in it the sanction of war and conquest, while pacifists saw the power of physical force transmuted into the power of intellectual and moral persuasion. Mill's doctrine was taken to be a sophisticated form of natural selection, in which the war of arms and might yielded to the war of words and ideas. Some complained because it exalted men to the level of supermen or gods; others because it degraded them to the status of animals. Political theorists read it as an assertion of the need for inequality in the social order corresponding to the inequality in nature, or alternatively as an egalitarian tract in which men as well as animals were in an undifferentiated state of equality. Bertrand Russell did not see how a resolute egalitarian could resist an argument in favor of "Votes to Oysters."

Periodically, a work on the nineteenth century will come along to declare that Darwinism "placed all political and social problems in a new perspective." The truth, however, is probably more with Herbert Spencer, who, having devoted his life to just this task of placing all political and social problems in the new evolutionary perspective, finally confessed: "The Doctrine of Evolution has not furnished guidance to the extent I had hoped. Most of the conclusions, drawn empirically, are such as right feelings, enlightened by cultivated intelligence, have already sufficed to establish."

NOTES

[1] "Darwinism" may, of course, be used to refer to the scientific doctrine itself. In this context, however, it is meant to apply particularly to the social, political, moral, and religious theories based on the scientific doctrine.

[2] *Athenaeum*, XXXIV (1859), 268.

[3] Dorlodot, *Darwinism and Catholic Thought*, p. 6.

[4] Russell, *Month*, Jan. 1956, pp. 41, 45.

[5] Adams, *Education*, pp. 225–26.

[6] Huxley, "The Interpreters of Genesis and the Interpreters of Nature" (1885), *Essays upon some Controverted Questions*, p. 89.

[7] Coleridge, *Biographia Literaria*, p. 63.

[8] Dewar and Shelton, *Is Evolution Proved?*, p. 5.

[9] Davey, *Darwin, Carlyle and Dickens*, p. 26.

[10] Julian Huxley, *Religion Without Revelation*.

[11] Haeckel, *Last Words on Evolution,* p. 112.
[12] Agassiz, *Methods of Study in Natural History,* p. iv.
[13] Hutton, "The Materialists' Stronghold" (1874), *Aspects of Religious and Scientific Thought,* p. 48.

DIALECTICAL MATERIALISM AND SOVIET SCIENCE *

Lewis S. Feuer

Professor of Philosophy at the University of California at Berkeley, Lewis S. Feuer has written several works on Marxian thought. The following article discusses the danger to science of adopting an ideology that logically predetermines ideas.

. . . The contemporary Soviet theory of knowledge is most accurately classified as a species of pragmatism. The terminology employed is dialectical, but like the Hegelian vocabulary of John Dewey, it conveys a doctrine which is pragmatic. The crudities of Soviet pragmatism are analogous to those in Dewey's philosophy at the turn of the century. We might even affirm that Soviet philosophy today largely resembles American philosophy of forty years ago. This philosophic similarity, moreover, seems to arise from similarities in the technological status of both countries. Industrial productivity in Russia in 1928 was roughly identical with that of the United States in 1904, and there was furthermore a "close proximity of the general level of wage variation in different industries in the U.S.S.R. in 1928 and in the United States in 1904." [1] The America of 1904 was only recently emerged from its pioneer days, and its emphasis was on the requirements of capital construction. The Soviet government has likewise in its economic planning given priority to the requisites of capital formation, and with this emphasis, there has also gone the epistemologic corollary that scientists' efforts should be directed toward practical, socially useful ends. . . .

* L. S. Feuer, "Dialectical Materialism and Soviet Science," *Philosophy of Science,* April 1949, pp. 112–24.

As a socio-ethical matter, it may well be that the Soviet government is justified in demanding from its scientists work which is immediately useful. For the exigencies of economic reconstruction may require all the community's resources. Confusion arises, however, when a socio-ethical demand is not stated as such but is projected into an epistemologic proposition which asserts that only those statements can be "knowledge" which are useful for immediate industrial purposes. The prime source of traditional epistemology is the desire to project an ethical or ideological perspective into the definition of truth. The Soviet theory of knowledge, from this standpoint, is the counterpart of the Platonic theory of knowledge. Plato held that only those statements which were useless could be really "true." The Soviet theory holds that only statements which are useful are really "true." Both theories are ideological intrusions into the scientific conception of truth, and both interfere with scientific work.

The Soviet theory of knowledge universalizes into an all-embracing epistemological definition of truth something which reflects the immediate practical requirements of an historically conditioned situation. The statement "we desire knowledge which will be of immediate practical value" is translated as the definition "knowledge consists of propositions which have an immediate practical value." An ethical proposition is thus given concealed form as an epistemologic proposition.

The Soviet theory attempts to demonstrate its central epistemologic proposition as a theorem in the sociology of science. The history of science does not support the thesis that every scientific statement is a proposed solution to some immediate social or technologic problem.[2] Soviet writers rely, however, on a "dialectical" sociology of science. Bukharin, for instance, notes (much in the way Dewey has done) that the separation of theory and practice is a reflection on the separation of intellectual and manual workers. This separation, harmful to science, is only overcome by the Soviet society where there is a unity of theory and practice, founded on the "primacy of practice." [3]

Now the "primacy of practice" is a sound precept if it is taken as identical with the scientific principle of verifiability. It then holds that no theory is meaningful unless it leads to some verifiable consequence. In addition to this scientific sense, however, Soviet thinkers use "primacy of practice" as the equivalent of "primacy of immediate practical need." Their doctrine then becomes a pragmatic one, for it imposes the following restriction on the scientific theory of meaning: that no theory is meaningful unless it leads to some consequence which contributes to the human control of the social and physical environment. The scientific and pragmatic criteria of meaning are obviously not coextensive, for there are scientifically confirmable propositions which do not contribute toward the solving of some practical, human problem. The dialectic vocabulary in the Soviet Union is used however to blur this distinction. "Primacy of practice" is referred to as the "practical criterion of truth," and by an illicit ambiguity, the principle of verifiability is taken as identical with the pragmatic criterion.

From the Soviet standpoint, scientific theory is a special case of the "unity and struggle of opposites." Man, a part of nature, copes with his environment, and scientific thinking is a response to a conflict situation. Like Dewey's early pragmatism, no theory is significant unless it is a response to some problem stimulus in man's socio-biological environment. Every proposition of science is then a tool in man's dialectic struggle with the environment. The Soviet ambiguity concerning "primacy of practice" imposes on those who use scientific method a commitment to a "social usefulness" criterion of meaning. A semantical concept is confused with a cultural, pragmatic motive.

Eric Ashby has vividly described how the dialectical terminology is used as the vehicle for a narrow, pragmatic doctrine:

> "The idea of struggle which permeates the writings of Lenin and Stalin, has flowed into the remotest channels of Soviet social life. We read of struggle against drought, struggle against beetles, struggle for the harvest, and so on. 'There is no conception more fundamental to Soviet Communism,' say the Webbs, 'than that of man's perpetual struggle toward a greater command of the universe in which he finds himself.' And with the idea of struggle goes a reckless optimism, a bravado almost, in large-scale technical research and in far-distant exploration. The plant-breeder is not merely working at plant selection: he is 'remodelling' crops for socialist agriculture. The agronomist is 'liquidating' low yields. The explorer is 'conquering' the desert. The 'struggle against the Arctic' is a striking example of enthusiastic team-work for the 'mastery of Nature,' . . ." [4]

The laws of dialectic confer a further unique restriction on the Soviet theory of truth. According to the dialectical sociology, every new form of society must have its corresponding new methods of science. Soviet society must thus have methods of scientific work which are qualitatively peculiar to a socialist economy. Scientific logic is raised to a new level which makes possible the solution of problems which scientists in non-socialist countries cannot solve. The emergence of Soviet science thus illustrates the dialectic patterns of "change of quantity into quality" and "negation of negation." Soviet science, moreover, is an agency of Soviet planning, to the success of which it must contribute. Hence, any scientific theory which does not lead to the envisagement of an immediately expanded economic productivity is to that extent dubious and suspect, for such a theory lacks the earmarks of the qualitatively novel approach which is supposed to surmount obstacles to the successful working of socialism. "There is no fortress," says Stalin, "that bolsheviks cannot take by storm." And, conversely, every theory which differs qualitatively from the conventional scientific theory of our period but which if it were true, holds forth the promise of an expanded productivity is to that extent to be welcomed.

Soviet pragmatism would thus differ from bourgeois pragmatism; for the methods of its science would differ qualitatively from the methods of bourgeois science. "Soviet verifiability" to that extent would differ from "bourgeois verifiability." The proof of the Soviet superiority would lie in the higher productivity statistics of the Soviet economy.

An element of wish-fulfillment enters the Soviet philosophy by way of the dialectic vocabulary when it maintains that Soviet science must be on a higher level than science elsewhere. Soviet philosophy is then a variant of pragmatism in the very sense in which Marxian philosophers define this term: "Pragmatism means that instead of allowing truth to reflect objective reality whether we like what we see or not, we construct a version that suits our desires and see whether we can maintain it in face of the facts. For so long as we can do so this version is truth." [5] Objective reality as misread in accordance with Soviet social policy is a species of pragmatism.

Like American pragmatism, Soviet philosophy stresses the "social nature of man." Bukharin even conceded that the "instrumental criterion of truth" coincides with the dialectical materialist criterion provided that allowance is made "of an instrument for the practice of social man." [6] Here, again, there is a misleading ambiguity in the use of "social." Science is social in one basic sense, namely, that in which it is taken for granted that other scientists will check on your work. The Soviet theory of knowledge adds to this another sense of "social." A scientific theory, according to the Soviet sense, must assist men in their activities in society, in their social problems. A sense of "social" which refers to verification as a social process is illicitly identified by Soviet thinkers with a theory of the social motivation and purpose of science.

The parallelism between Soviet and American pragmatism reaches far back into the historic backgrounds of both countries. Thomas Masaryk, in his classic study of Russian thought, noted that Russian philosophers in the nineteenth century had no interest in the more abstract problems of philosophy, but were drawn to practical questions.[7] Russian like American thought in the nineteenth century was predominantly devoted to sociological and religious questions. And in both countries, under similar technologic conditions, forms of pragmatism emerged as their first distinctive modes of philosophic expression, modified in each case by the respective social and political peculiarities.

The history of science shows that an erroneous philosophic theory may, none the less, harbor insights which promote the development of science at a given period. At a later stage, that same philosophic theory may become a hindrance to the further, unfettered development of science. Such is now the case with dialectical materialism in its contemporary expression as Soviet pragmatism. Soviet philosophy is now exercising a deleterious effect on Soviet science, and is indeed interfering with the basic objectives of a socialist, planned economy. This can be seen if we briefly examine the influence of Soviet philosophy on physical science, economics, and biology.

a) Soviet philosophy has hindered its physicists from participating to the maximum in great advances in physical science. Lenin's authority was controlling upon the minds of many Soviet thinkers, and they noted that he criticized adherents to the theory of relativity. "The overwhelming mass of representatives of the bourgeois intelligentsia in all countries" Lenin wrote, "has fastened upon Einstein's theory. . . ."[8] Beginning with this discussion in 1922, the majority of Soviet philosophers and physicists rejected the relativity theory as idealistic and metaphysical. Einstein's adherence to the principle of observability was regarded as an affiliation with Ernst Mach's "bourgeois" empiriocriticism.

After twenty-five years of "impassioned discussions," the theory of relativity was finally assimilated within dialectical materialism. "The battle of ideological principles" was declared over, and a Soviet official report concluded "that our philosophical conclusions concerning the theory have been firmly established." It was now affirmed that the "real scientific-physical side of the theory of relativity" is "a step forward in discovering the dialectic laws of nature." "Our science, armed with the method of dialectical materialism, proved to be able to give a real assessment of the role and significance of this theory. . . ."[9]

This Soviet report makes it clear that dialectical materialism retarded the development of Soviet physical science. Western scientists, not bound by any necessity of adjudging the accordance of relativity theory with some special philosophical formula, accepted it on its own evidence, and proceeded to further work. Soviet scientists and philosophers spent twenty-five years catching up to Western theory until they could invent phrases about the "dialectical unity of time and space," and accustom themselves and others to talking about relativity in dialectic vocabulary. The linguistic habits of dialectical materialism were not a source of flexible analysis of facts, but rather a time-consuming restriction upon the use of the available scientific resources.

Soviet pragmatism, moreover, has recently been showing renewed narrowing tendencies. Under the impact of the growing political tension with the Western world, dialectical materialism is again being used as the basis for a critique of relativity physics. The secretary of the Central Committee of the Communist Party of the Soviet Union, A. A. Zhdanov, declared in an authoritative statement: "Many followers of Einstein, in their failure to understand the dialectical process of knowledge . . . transpose the results of the study of the laws of motion of the limited sphere of the universe to the whole infinite universe and arrive at the idea of the finite nature of the world, its limitedness in time and space." After thus criticizing the use of finite, non-Euclidean cosmologic models as "non-dialectical," Zhdanov goes on to denounce Milne's attempt to calculate the age of the world.

How meaningless the criterion of "dialectical" can become is shown by the fact that Haldane praises this very aspect of Milne's cosmology for its beautiful "dialectical nature." Haldane finds that Milne has introduced the historical process into physics. According to Milne's theory, the world's atoms were once concentrated into a small volume: with the evolution of the universe, the laws of nature changed due to the "contradictions" between the time scales of radiation and the movement of masses. Milne's cosmology, Haldane concludes, is the "most dialectical" of all.[10] There seems to be no scientific basis for deciding on the rival usages of "dialectical" by Zhdanov and Haldane.

Zhdanov speaks slightingly of "these English scientists." Herein the word "dialectical" acquires a nationalist significance. The significance of Soviet philosophy is then to legislate the "true" principles of the universe with a super-scientific authority. The geometry of the universe is enunciated by dialectic fiat; geometry, as the statement of verifiable relations among events, is secondary.

Soviet physicists who bear the baggage of their philosophic doctrine are impeded in their work. They must be mindful that their methods conform not only to the facts but to the dialectic ideology; the two conditions cannot both be always satisfied. Perhaps the failure of Soviet physics to achieve the Western successes in atomic theory and invention are partially due to the wasteful influence of the philosophy of dialectical materialism.[11]

b) The philosophy of dialectical materialism has led to confusion in the field of Soviet economic theory. This has been especially evident in the efforts of Soviet economists to analyze the laws of socialist economy. The dialectic methodology was taken to prescribe the advent of a novel system through a "negation of negation." The contradictions of the previous system are solved only through the emergence of a "new law-system." Soviet economists took heed that their system must be *new*. They held therefore that the laws of socialist economy must negate the laws of capitalist economy, and they likewise concluded that the economic theory of value and marginal calculations can have no significance in the socialist domain. Engels had written that with the advent of socialist production "people will be able to manage everything very simply without the intervention of the famous 'value.' " The concept of value, Engels had maintained, was an expression of commodity production, and it was a violation of "negation of negation" to try to analyze socialist economy with a category which was an expression of capitalist economy. Soviet theorists tried to conform to the mandates of the economic dialectic.

The actual requirements of accounting and administration were however at variance with the dialectic dictates. Categories like value, profit, and interest were of essential use to socialist economic planning. A commission on economic theory undertook in 1943 to interpret the dialectic in a manner closer to practical requirements. Its liberal rendition of dialectic methodology coincided with a period of relative political rapprochement between the Soviet Union and the capitalist world. The commission affirmed that substantial mistakes had been made on the question of the character of the economic laws of socialism. It had been incorrectly assumed that "if under capitalism there existed such and such a condition, such and such a law, such and such a category, then in the Soviet system of economy it is altogether absent, altogether the opposite." The commission asserted the "correct" meaning of the economic dialectic as follows: . . . . "the law of value is not abolished under socialism, but exists, although it operates under different conditions, in different surroundings, and its operation is very substantially changed from what it was under capitalism."

What should be noted is that the Soviet economic commission has, in effect, repealed the "negation of negation." The latter originally was taken to mean that one law-system was superseded by another which was its qualitative negative. Now, however, it was being taken as equivalent to the ordinary principle of scientific logic that a general law may have different special forms under different initial conditions. The Soviet theorists now acknowledge as a general law that "surplus labor must always exist in any social order." As in the case of the physicist's reception of relativity theory, Soviet economists were led to waste much time by the constraints of "negation of negation." Their analysis was obfuscated by the dogma that socialist laws must completely negate capitalist laws. Finally, as Oscar Lange states, their theory began to converge on that held by Western students of socialist economics.[12] The dialectic philosophy had only operated to retard Soviet economic theory behind Western theory in the study of the workings of socialism.

c) No branch of science has been injured to such an extent as has Soviet genetics by the influence of the dialectic philosophy.

The story of N. I. Vavilov is among the world's scientific tragedies. Vavilov, the outstanding Soviet geneticist, had, as president of the All-Union Academy of Agriculture Sciences, directed extensive researches which placed Soviet genetics in the forefront of world science. A student of Bateson, Vavilov's work was in accord with accepted genetic methods and principles. Beginning in 1935, an attack was launched against Vavilov by a plant physiologist, T. D. Lysenko, associated with a philosopher, I. I. Present. Vavilov's work was said to be inconsistent with dialectical materialism. It was intimated moreover that his methods had slowed down the development of Soviet agricultural production by failing rapidly to assist animal and plant improvement. Soviet pragmatism was in the ascendancy, and Vavilov was charged with having dissipated scientific energies in foreign expeditions instead of concentrating on Soviet local varieties.

A campaign to discredit Vavilov achieved its objective at the Moscow conference on genetics in 1939. The dialectical materialist Mitin declared that "precisely because Academician Vavilov is a leading scientist, our collective society has the right to make demands upon him that are by no means small: namely, to come closer to life, to practice, to bridge the gulf between science and practice." A component of nationalism was introduced with the warning that "it is not necessary for you to bow slavishly before foreign science." Vavilov was subsequently arrested, imprisoned in a concentration camp, transported to Siberia; he died, probably in 1942.

Concerning Lysenko, the opinion of scientists sympathetic to Marxism is that "there is no evidence that he has ever read any genetical work published since, say 1910, and the system by which he proposed to replace genetics is a muddle of propositions which are mutually contradictory wherever they are not meaningless." A standard American textbook (with Dunn as one of its authors), is "passed in secret from student to student as though it were an inflammatory tract." Lysenko in the meanwhile rose to positions of political and scientific eminence.

The dialectic philosophy supplies Lysenko's school with a set of first principles which accredit their biological doctrine. Since the dialectic avers that all matter is in a state of flux, Lysenko argues that "there can be no stable, hereditary characters, independent of the environment; no so-called 'pure lines,' or constant varieties of crops." Lysenko's school cannot acknowledge that the intractability of living matter sets limits to the rapid improvement of crops. "The disciple of Lysenko cannot resign himself to the stability of nature. Nurture must take charge over nature, at any rate within the boundaries of the Soviet Union: for it is a principle of dialectical materialism that it should be so." To bring genetics into conformity with Soviet pragmatism, the constancy of the Mendelian genotype is criticized as contrary to dialectical materialism.

No geneticists, of course, claim a metaphysical immutability for the genotype. The study of mutations and changes in chromosome structure during cell division are studies of processes which are not pursued in any Parmenidean spirit. The Mendelian genetic theory, moreover, conforms to the dialectic schemas just as well as Lysenko's. What Lysenko further demands of the dialectic formulae is that they satisfy a set of pragmatic demands. The principles of Mendel and T. H. Morgan must be rejected because they tend to place limits to the revolution in the productivity of socialist agriculture. Soviet agriculture demands a novel science which will be the negation of bourgeois genetics. Lysenko's followers also denounce the use of the mathematics of probability in genetic science. They regard this as a part of a "metaphysical and idealist trend." "According to Morgan," they say, "living nature is a chaos of accidentally-scattered phenomena, devoid of necessary connections or regularity. All the so-called laws of Mendel and Morgan are built on the idea of accident—but genuine science is the enemy of accident." Lysenko's school would thus condemn all the employment of statistical methods in science. Statistical mechanics, quantum physics,—all would be regarded as not "genuine science." Soviet pragmatism thus outreaches itself into a metaphysical criterion of scientific theory.

Pragmatic projection, political wish-fulfillment, thus become a substitute for experimental methods. The formulae of dialectical materialism are flexible enough to cloak any sort of ideological intrusion into science. Lysenko's school regards any proposed process as "dialectical" if it conforms to socio-economic needs. "Dialectical" thus becomes an adjective describing the relative rapidity of a rate of change which is conducive to the success of socialist agriculture in the development of new crops. Soviet pragmatism desires a world in which biologic revolutions occur more frequently; its world is less "static" if environmental factors like temperature conditions can modify winter varieties into spring varieties.

Scientists generally have found Lysenko deficient in the comprehension of statistical and experimental methods. When confronted with contrary experimental evidence, Lysenko avails himself of picturesque rhetoric concerning "bourgeois Mendelians." His doctrine moreover abounds in unverified *ad hoc* hypotheses such as the mechanism of the "assimilation" of sex-cells. Dialectic speculation thus tends to overshadow experimental fact. Soviet pragmatism, moreover, has retarded the advance not only of Soviet biology but also of Soviet agriculture. It is a fact of importance that Soviet plant-breeding cannot claim such successes as hybrid corn and rust-resistant wheat which were developed in America by genetic methods. Lysenko's pragmatic dialectic has been a factor in this retardation of Soviet economy.

When a philosophic terminology reaches the point where it confuses rather than clarifies scientific problems, when it loses significance and has only slogan-value, then it is clear that the time for its obsolescence in the history of science is at hand. Thus, a law of dialectic like "negation of negation" has been transformed into an empty form which derives its content from socio-pragmatic projection. The philosophy of dialectical materialism is thus an impediment to the development of Soviet science.

Soviet pragmatism is also isolating Soviet science from the currents of world scientific advance. During the cooperative phase of the world war, there was a growing tendency for Soviet science to merge its thinking with the general lines of world science. In 1945, the physicist Kapitza could assert that "there is really no such thing as Soviet science, or British science: there is only one science, devoted to the betterment of human welfare. Science must, therefore, be international." And Kapitza during those years could also sharply rebuke the doctrines of Soviet pragmatism. The later years, however, have brought a renewed insistence on pragmatism and an intense emphasis on the uniqueness of Soviet science. The geneticist Zhebrak had in 1945, for instance, sought to interpret dialectical materialism as a philosophy "based on real facts," and therefore in accord with genetic principles and scientific theory. Two years later Zhebrak's article was denounced as an anti-patriotic act written under the guise of "scientific" criticism, and he was criticized for his adherence to "pure science," and for his "contemptible subservience to bourgeois science." Zhebrak in his letter to *Science* in 1945 had dared to assert that "the statements of Lysenko concerning the supposed refutation of Mendel's laws on the basis of dialectical materialism have little in common with the serious development of philosophy in the Soviet Union." He expressed the hope that Russians would work with Americans to build a "common, world-wide biology." Philosophic friends of Soviet policy took solace in the fact that Zhebrak and his school were allowed to continue research along their chosen lines despite Lysenko's political preeminence. Within three years, however, Zhebrak was forced to relinquish his academic posts, and to recant his scientific views with the statement: "I as a party member, do not consider it possible for me to retain the views which have been recognized as erroneous by the Central Committee of our party." Scientific theory was being overruled in favor of socio-national pragmatism.

Nationalist interpretations of the history of science and philosophy have come to the fore in the Soviet Union, and have supplanted the classical Marxian international perspective. The history of science is being re-told with an abundance of extravagant Russian claims to priorities. And the leading Soviet philosopher summarized the history of modern philosophy as follows: "With the exception of Marx and Engels, the 19th and 20th centuries gave no philosophers who can compare with Herzen and Belinsky, Chernyshevsky and Dobrolyubov, Plekhanov—the pioneer of Marxism in Russia, Lenin and Stalin—the great scholars and leaders of advanced science in the 20th century."

Western scientific philosophers like Russell and Poincaré are assigned to the lower brackets by the nationalist canons of evaluation. Soviet philosophic thought itself meanwhile has metamorphosed into a species of academic Marxian scholasticism. Although Soviet leaders call for original work in logic, philosophy of science, and historical materialism, Soviet scholars prefer to avoid "unsafe subjects" with their concomitant risk of deviation. They therefore direct their energies to the history of philosophy rather than contemporary issues. Soviet practice thus tends to promote a disunity between theory and practice.

The sociological problem inevitably confronts us: are the abuses of Soviet science the necessary outcome of a centralized socialist society? The evidence does not warrant an affirmative conclusion. We have seen that motivations of a pragmatic and national kind have come to predominate in Soviet thought. These motivations do not stem from the character of socialist economy. They have flourished in capitalist societies, and we can only infer that common technologic and political problems will produce similar ideological responses in both socialist and capitalist countries. The chemist Ipatieff has in his autobiography given much information concerning the relations between scientists and the central planning agency. With a few substitutions, his account could be taken as one concerning the relations of American scientists and large industrial research foundations:

"The Sovnarkom also decided that thereafter the first duty of the Academicians would be active participation in the Socialist construction of the U.S.S.R., which would imply a close relationship between their work and that of industry. . . . Members of the Academy hopelessly tried to show that since the Academy of Sciences represented the highest scientific institution in the republic, its primary purpose should always be progress in science as a whole, even though specific discoveries might not find immediate industrial application. . . . History teaches that scientific discoveries have always been made when men were unfettered by rules or arranged programs. No matter what plan of scientific research is drawn up, even for a period of a year, no scientist, if he be free, will carry it out to the letter; for it is of the very essence of research that he discover new unforeseen occurrences which force him to lay aside his entire planned program and study some some new fact. Every scientist considers this so self-evident as to need no proving. The Soviet Government ignored this. It insisted that henceforth the new Academy of Sciences was to conduct its research according to programs decided upon by the government and that even independent research was to be devoted to the problems of industry—scientists must eschew the temptations of pure science."

Where practical industrial motives dominate the structure of a society, the pragmatic philosophy will flourish. And this philosophy will finally retard the scientific work of a society, no matter whether it be capitalist or socialist. But where the society's scheme of values allows for disinterested research, socialist planning will not carry with it constraints on science. The pragmatic ideology is not the necessary expression of a planned economy. Nor would a wisely planned society commit itself to an epistemology which asserts that scientific investigation into areas can be conducted like an assembly-line operation. The unforeseen datum, the accidental fact, is often crucial in the history of science, and it lies outside the purview of the epistemology of planned scientific research. Socialist organization could allow for the distinctive character of the free development of science, and leave large unpatterned segments in its economic plan.

The Soviet society has made pathfinding contributions to two of the world's great problems—those which concern the mechanics of economic planning and cooperative relations among different peoples and races. Among those questions which it has yet to solve is the establishment of a free science. Soviet philosophers of science often urge a return to their national heritage of scientists like Timiriazev. Such a return might well be welcomed. Soviet thought would then draw important truths from Timiriazev's philosophy as a scientist, and the strident tones of Soviet pragmatism might be abated:

> . . . "this practical tendency, which characterises the infancy of a science, cannot and must not be its aim. Throughout the development of a pure science its results find application spontaneously. The development of a science can be determined only by the logical sequence of its achievements, never by the external pressure of necessity. Scientific thought, like every other form of mental activity, can work only under conditions of absolute liberty. Oppressed by the weight of utilitarian demands, science can produce but pitiable artificial work, after the same kind as any meagre and mechanical work of art fashioned under similar circumstances. We may ransack the archives of any science and yet find scarcely one daring idea, one brilliant generalisation which owed its origin to its application, and, vice versa, history is full of examples of discoveries, which, though unassociated with any practical purpose, have become the source of innumerable practical issues."

We have tried to show in this essay the following:

(1) that dialectical materialism, while calling attention to some of the possible forms of laws of nature, turns from science to ideological metaphysics when it maintains that these forms are the privileged standard forms of laws of nature,

(2) that dialectical materialism, in its present guise of Soviet prag-

matism seeks to impose such forms of laws as (a) are isomorphic to the structure of a revolutionary social transformation, (b) as would make possible, if true, immense gains in agricultural and industrial productivity, and (c) are not held by the generality of Western scientists,

(3) that this philosophy, with its mixture of ideological, pragmatic, and nationalist motives is now retarding the advancement of Soviet science.

NOTES

[1] Abram Bergson, *The Structure of Soviet Wages,* Cambridge, 1944, pp. 80–81, p. 209.

[2] Cf., V. F. Lenzen, "Science and Social Context," *Civilization,* University of California Publications in Philosophy, Vol. 23, Berkeley, 1942, p. 23.

[3] N. Bukharin, "Theory and Practice from the Standpoint of Dialectical Materialism," *Science at the Cross Roads,* loc. cit., pp. 14–15, 27.

[4] Eric Ashby, *Scientist in Russia,* Penguin, Middlesex, 1947, pp. 117–118. B. A. Keller writes: "The Soviet scientist differs radically from the usually accepted conception of a savant. Borrowing the words of Karl Marx, scientists formerly resembled philosophers who only explained the world differently; the Soviet scientists of today are working to change it." *The Soviet Scientist,* Moscow, 1939, p. 13.

[5] M. Shirokov, *A Textbook of Marxist Philosophy,* translated and edited by John Lewis, London, 1937, p. 85.

[6] N. Bukharin, *op. cit.,* p. 18.

[7] Thomas Garrigue Masaryk, *The Spirit of Russia,* transl. by Eden and Cedar Paul, London, 1919, Vol. I, p. 200.

[8] V. I. Lenin, *Religion,* New York, 1933, p. 33.

[9] Acad. M. Mitin, "Twenty-five Years of Philosophy in the U.S.S.R.," *Philosophy,* Vol. XIX, (1944), p. 81.

[10] J. B. S. Haldane, *The Marxist Philosophy and the Sciences,* pp. 67, 76. *Dialectical Materialism and Modern Science,* loc. cit., p. 268. Haldane has tried to develop Milne's ideas in "A New Theory of the Past," *American Scientist,* Vol. 33 (1945), p. 129.

[11] [Recent Soviet successes in atomic theory and invention, of course, have caused us to re-examine our earlier conclusions about the place of science in an authoritarian society. The Editor.]

[12] Oscar Lange, "Marxian Economics in the Soviet Union," *American Economic Review,* Vol. XXXV (1945), p. 131.

SCIENCE IN MODERN SOCIETY; ITS PLACE IN LIBERAL AND IN AUTHORITARIAN SOCIETY *

Bernard Barber

Bernard Barber, Professor of Sociology at Barnard College, has written extensively on the sociology of science. In the following selection he describes the ideal values for science, and their congruence with Western liberal society.

After our account of the historical development of science, we can now understand in just what sense it is true, as we so often hear, that science is unique in modern society. Our science is not unique in kind but rather in its extremely wide scope and in its high degree of development. Only in modern society do we find that peculiar combination of elements which has evolved out of earlier forms of empirical rationality and which is indispensable for science as we know it—very highly generalized and systematized conceptual schemes; experimental apparatus which greatly extends man's powers of observation and control of data; a relatively large number of professional scientific workers; and, widespread approval of science in the masses of the population as well as in the elites.

This combination of elements, this science we know and take for granted, is not, however, random, nor is it inevitable or immutable. Recent events in Nazi Germany and in Soviet Russia have suggested that some parts, at least, of science may decline as well as grow, perhaps even be stifled altogether. Science, in short, is not only dependent on its environing society, as we have seen in the preceding chapter, but is more congruent with some types of social conditions than with others. This relationship between science and modern society has recently been

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noted by Professor Talcott Parsons. "Science," he says, "is intimately integrated with the whole social structure and cultural tradition. They mutually support one another—only in certain types of society can science flourish, and conversely without a continuous and healthy development and application of science such a society cannot function properly." [1]

. . . .

Every human society has a set of cultural values, a set of moral preferences for certain kinds of social activities as against their alternatives. Let us turn first to the system of cultural values which characterizes the modern world as against other societies, the values which realize themselves not only in science but in a great many other social activities. This is the set of deeply rooted moral preferences which has made possible the uniquely high development of the science we know. This is the set of values we must maintain relatively strong if we wish to maintain science relatively strong. These values are not, of course, officially nor even informally codified, so the particular list we give here can only be offered as the consensus of numerous scholars and moral leaders who have tried to discover them. Any similar listing would, however, probably have a very large overlap with this one, especially when merely verbal differences were eliminated by close analysis. In any case, these are the values that are significant for science and other essential activities in modern Western society, even if it is difficult to draw them up in precise and final hierarchies.

One of the key cultural values we have to speak of is the value of *rationality*, and the congruence of this moral preference with science is obvious. We are not now referring just to the practice of rationality, for as we have seen that occurs in all types of society. By the value of "rationality" we mean the moral, the emotional, the "institutionalized" as the sociologist says, approval of that practice throughout wide areas of the society. This approval results in the critical approach to *all* the phenomena of human existence in the attempt to reduce them to ever more consistent, orderly, and generalized forms of understanding. Rationality of this kind is specifically different from what has been a predominant characteristic of all previous types of society, namely, the cultural value of "traditionalism." This value approves the acceptance of whatever exists, on its own terms, simply because it has always existed, without wishing to criticize it in terms of rational consistency and generality. The "rational bent" of modern man, which Thorstein

Veblen was one of the first to compare with the habits of men in other societies, leads modern man to question the world in every direction, to analyze all that has been passed down to him merely by the "rule of custom." The modern world thinks the rule of reason more important than the rule of custom and ritual.

This value of rationality underlies much more than science in our society, although it is most strikingly manifested there, of course. For example, our economic activities can only be maintained in their present form because of the widespread diffusion of this value in the population. The moral norm for behavior in the economic area, that is, is a rationality of which efficiency in industry and a skillful orderliness in all affairs are the outward signs. When we praise "the spirit of free inquiry" we are referring to another aspect of our value of rationality. That spirit is chiefly exercised by the professional groups and especially by the scientists among these, but it is a cultural ideal in all social groups. Every man, we say, has the right to ask questions and to satisfy "himself," by which we refer to his reason. Indeed, this is not merely a right, but a duty. That is to say, there is a notably active quality about the value of rationality in our society. It requires man to strive for rational understanding and control of all his affairs by a perennially active effort, not just when events baffle or thwart him. In science itself, this spirit of rationality becomes an institutionalized self-generation of endless inquiry, ever novel and ever more general hypotheses. No realm of the world or of society is now immune to penetration by the active rationality prescribed by our cultural approval of it.

Inevitably, of course, as we well know, this active rationality comes into conflict with certain established habits and activities in society, for example, with the "sacred" beliefs of religion or with ancient economic mores. These other activities resist the "attacks" of rationality, sometimes violently, more often in our recent history by giving way slowly in adaptation to the corrosive effects of unbounded inquiry. We shall look into the sources of this resistance to rationality and into its significance for science more closely when we discuss, later on, the social consequences of science. What we need to remark at this point is that, on the whole, the relative strength of the value of rationality continues to prevail, despite counter-attack and resistance from some of the things it questions and criticizes. Especially as it is embodied in the structure and consequences of science, thus, active rationality is the source of the great dynamism which sets its mark on the modern world.

We need a term for another important cultural value of the modern world and we shall use the term "*utilitarianism*" for this purpose, even though it has certain connotations which we do not here imply and which we shall therefore specifically exclude. By the value of utilitarianism we mean that predominant interest modern man has in the affairs of this world, this natural world, rather than in other-worldly affairs such as supernatural salvation. This value is also obviously favorable to a high development of science. Modern rationality, in contrast to, say, the rationality of the Mediaeval world, is primarily rationality applied to the empirical phenomena of everyday life. In our discussion of the rise of modern science, we indicated that this everyday empirical rationality was derived in some part from the active interest in this-worldly affairs prescribed by The Protestant Ethic of Calvinism, an interest which has been so well analyzed by Max Weber. By now, however, this interest in mundane activities has become almost wholly autonomous, almost wholly based on secularized derivatives from the earlier religious interests, as well as on the consequences of other developments. But perhaps this partial source of utilitarianism in what were specifically religious interests should make it clear that the value of utilitarianism is *not* necessarily and invidiously "materialistic." There is no identity between materialism and utilitarianism, as some who have opposed this latter value maintain. Although materialism is a possible consequence of utilitarianism, so is an "idealistic" concern for the affairs of this world also possible. The evidences of idealistic utilitarianism are widespread in social reform and social voluntarism. The most vivid evidence of all for the existence of idealistic utilitarianism, however, may be found in science itself. This too we shall refer to again, when we outline the specific cultural values of science as an independent social activity.

The approval our culture places upon *universalism* constitutes still another value which has a special congruence with the maintenance of a high level of scientific activity. This value, derived from and still expressed most fundamentally in the Christian ideal of the brotherhood of man in God, has a secularized meaning in modern industrial society. It means that, in this society, ideally, all men are free to find that calling in life to which their merits entitle them. It means that each man's station in life is consequent upon his achievement in his calling, that is, in an industrial society, in his "job." Every man may compete for any occupational function and for any specialized position within the hierarchy of an occupation. Quite specifically, for example, any man who has the talent for the job of being a scientist and who has the desire to take up the job, has a social right to do so that is as great as that granted to all other men. As the American expression of the value of universalism has it, a man may become a scientist regardless of race, color, or creed. Moreover, once a man has become a scientist, he has the right to be treated by all fellow-scientists and by all fellow-citizens in terms of the universalistic norms which apply to all who have that job and that status. Where the value of universalism is realized fully, Jews and Negroes are not barred from science or any other occupation. And in science itself there is no "Catholic" science and no "Jewish" science and no "German" science. Universal science flourishes in those parts of the modern world where the value of universalism is most nearly realized.

Another cultural value which has great scope in the modern world in contrast with other societies is the value that we shall call *individualism.* By this value we mean the moral preference for the dictates of individual conscience rather than for those of organized authority. We have the libertarian conviction, derived in part, as is *utilitarianism*, from Protestant theology, that it is our duty to seek the inspiration for all behavior in our own consciences. Modern man grudges the sway of organized authority in a fashion that is new among societies. This is an attitude which is most congruent with science, for science rejects the imposition of any truth by organized and especially by non-scientific authority. The canons of validity for scientific knowledge are also individualistic: they are vested not in any formal organization but in the individual consciences and judgments of scientists who are, for this function, only informally organized. Some of the resentment which scientists feel against so-called "planning" in science, as we shall see more fully later when we discuss this subject, derives from their individualistic fear that formally organized authority will be substituted for the informal judgments of peers in the control of science.

One last cultural value of the modern world seems to be important, and that is the value placed upon *"progress" and meliorism.* There is, in present-day society, a widespread conviction that the active rationality we have discussed earlier can and should improve man's lot in this world. This is coupled with a belief in and an approval of "progress" in this world, a progress which is not necessarily of a unilinear evolutionary kind, but which is somehow cumulative in the way in which science and rational knowledge are cumulative. This value, too, has its source to an important degree in Christian perfectionism and Protestant activism. And of course our moral preferences for "progress" and meliorism have a positive congruence with the essential dynamism of science. On the whole, despite localized resistances and hostilities in particular cases, modern society has been cordially receptive to the innumerable innovations fostered directly and indirectly by the advance of science. If it be hard to live with the instability and change that science makes a permanent feature of our society, and we all know how hard it sometimes is, still our approval of science as an agency of "progress" and meliorism makes us more willing to sustain this condition, to take the bad with the good.

. . .

In addition to the cultural values that we have picked out, there are in the modern world, in contrast to other societies, certain social conditions which are especially favorable to a high level of scientific activity. We refer to such things as a highly developed division of labor, a social class system which permits of considerable social climbing, and a political system in which the autonomy of many diverse authorities is respected. Here too, in our discussion of these social conditions, we shall be constructing a model which is nowhere fully realized but only in differing degrees in different modern societies. These social conditions, or social structures as the sociologist might call them, are particularly congruent not only with science but also with all the cultural values that are characteristic of the modern world. They are not, however, merely derivative from those values. The two kinds of things are somewhat independent of one another, for all their possible congruences. For example, social action in terms of cultural values may have consequences that destroy social structures. This is what the Nazis were doing,—weakening their industrial system by their espousal of the cultural value of emotional irrationality. Contrariwise, of course, changes in the social structures of a society have consequences for its cultural values. For instance, the increasing value we put upon "security" as against "freedom" in American society is in part a consequence of changes that have occurred in our economic system. Because of these reciprocal influences between the different parts of a society, we have to consider, as we here shall, both the social structures and the cultural values. We turn now to these characteristic modern social structures, starting with the occupational system.

. . . .

Modern industrial society . . . has carried the division of labor to an extreme degree of specialization which has been hitherto unknown in human society. For example, taking the United States as a case, the Dictionary of Occupational Titles prepared by the United States Employment Service of the Department of Labor consumes more than a thousand pages in listing the titles and descriptions of the different jobs which exist in the country. The Dictionary defines some 17,000 different jobs, and this is admittedly not a complete list. In the American textile industry alone, there are about 1850 types of specialized skills. *Ideally,* moreover, these jobs are allocated on a basis which ignores differences of family connection. They are supposed to be distributive points in an occupational achievement system which is based on merit alone. This kind of specialized and family isolated occupational system is a late emergent in the history of human society and is fundamentally important for the successful functioning of an industrial type of society. It was for this reason that the Nazi attempt to re-establish "race" and family criteria for the assignment of occupational functions was a threat to its industrial system, however much the Nazis consciously may not have wished this consequence of their actions.

In the light of these variations in the division of labor that we have been describing, the occupational role of the scientist, let alone all its extremely specialized sub-divisions, is by no means a "natural" occurrence. Except within the last few hundred years, science has been very largely the by-product of occupational roles devoted to quite other tasks than that of the development of generalized conceptual schemes tested by technical observational devices. In doing his job the craftsman often produced substantial rational empirical knowledge, sometimes all unwittingly, sometimes self-consciously. But only in the modern industrial system, with its elaborate division of labor, is there a socially recognized and highly approved place for the "worker" whose job it is, and whose only job it is, to know science and to advance it. Indeed, such occupational positions do not appear full-blown until even later than the rise of modern science. We have seen that the great scientists of the sixteenth, seventeenth, and eighteenth centuries were typically "amateurs," or men for whom science was often an avocation, however passionate their interest in it. The men who then produced science often lived by other means, and they did their science as best they could, when they could. Benjamin Franklin was such a scientist, and a man of great scientific accomplishments. If the "amateurs" were particularly fortunate, they might find a patron who admired science and who would therefore give them funds for research. Society as a whole laid out no clearly marked and generally approved careers for scientists. Not until the late nineteenth century, as we shall see later in some detail, is there a firmly established social basis for large numbers of scientists in the universities, industries, and governments of Western society. And in the twentieth century, so much is the occupational role of the scientist taken for granted and approved, that we may wonder at the need for pointing out that this was not always so. With its very many different types of jobs, its extreme specialization, and its internal organization into professional societies—of which, too, we shall say more later—the elaborate occupational structure of science is now an essential part of the complex division of labor which is required by modern industrial society. This is as much true, we shall see, for a Communist industrial society like Russia as for a liberal industrial society like the United States or Great Britain. The continual advance of science now depends on this provision for a large number of occupationally specialized roles for scientific workers. Anything which diminishes this number and this specialization thereby potentially diminishes science.

The advance of science is in still another way related to the complex division of labor in modern industrial society. Not only are science and its products highly specialized, but an elaborate specialization of industry and technology is now required to use the production of science. In his very perceptive book, *Mechanization Takes Command,* Siegfried Giedion has recently shown that industrial technology of the kind we are familiar with is a function as much of certain kinds of social organization as of certain kinds of scientific knowledge. The industrial assembly line, for instance, is an important social invention in the division of labor, and modern machine technology is impossible without it no matter how much scientific knowledge we have. Therefore, since science and technology are now extremely interdependent and fructifying for each other, both are fundamentally dependent upon the maintenance of that great division of labor which is so essential a characteristic of modern industrial society.

The type of class system which is more characteristic of the modern world than of other societies, the "open class" system as the sociologists call it, that is, a system in which a relatively large amount of social climbing is approved, is also especially congruent with the maintenance of science at a high level. This is because of the functions which social mobility has in society. That is, whatever the causes may be—and they seem to be in part genetic, in part social and psychological—the social elite of a society in any given generation does not entirely reproduce its successor in the next generation. This is true no matter what skills are required of the elite, whether they be military, administrative, scientific, or other kinds of skill. In every society, therefore, some form of social reproduction of the elite is necessary, and this is achieved through varying amounts and types of social mobility in different societies. If the channels of mobility in a society, for example, are nearly closed, the elite may fail to reproduce itself in sufficient numbers, with consequent harm to the effective functioning of the society.

The necessity for social reproduction of the elite group in any given generation seems to be as great for science as it is for any other activity, perhaps greater. Because of the highly developed and highly specialized abilities which scientists must have, the advance of science requires that it be a "career open to talent," one in which ability occurring in the lower classes may climb into the professional scientific classes. And so it has been very largely in the modern world. Science would soon stagnate if its functionaries were mostly mediocrities whose occupational positions had been ascribed to them on the basis of their family affiliations alone. Other particularistic criteria besides family would be equally perilous to science. No "race" or nationality group or class has a monopoly on scientific ability. For this reason, the Nazis hazarded a great deal when they excluded so-called "non-Aryans" from the profession of science. An open-class system, providing opportunity for all talent to express itself, is most congruent with the advance of science. Of course, the relationship between these two is reciprocal. For by providing in each generation a number of highly esteemed positions which are open to achievement, science performs an important validating function for an open-class society. We may say that where men must and can rise, notions of social and racial caste will have a harder time of it.

Science has another important connection with the open-class system in the modern world. Although many different motivations attract men to specific occupational careers, the degree of prestige in the open-class system awarded to any given career is an important differential element in the choices men make among the occupational alternatives that are open to them. In modern society, science has a high class prestige. The job of scientist ranks near the top, as we shall see later, in public evaluations of the scale of occupational possibilities. Indeed, social respect for science and its practitioners is widespread even among those groups where there is considerable ignorance of its nature and functions. We shall see that this same consensus is characteristic also of Russian society, despite its interference with the activities of particular scientists. In Nazi society, on the contrary, there was at least an ambivalence toward the prestige of scientists and even an hostility which greatly depressed their social position. Men are less attracted to science when its social prestige is lowered. On the whole, the high social status which scientists have in the modern world symbolizes public recognition of the social importance of their functions. No modern industrial society can afford to lower that status very much or neglect those functions.

Like a highly developed division of labor and an open-class system, the type of political system which does not largely centralize its authority also is particularly congruent with science. This "liberal" type of political system is, of course, a peculiar product of modern society in contrast to other types of social system, even though its incidence is partial even in the modern world. As we shall see more fully later, in the highly developed state to which empirical science has now arrived, its effective functioning requires a large degree of freedom from certain restrictive kinds of external control. Science cannot advance without a large amount of self-control, by which we mean control by the professional scientists themselves in their informal and formal organizations. This essential autonomy has, by and large, been granted to science in the modern world. Before the rise of modern science, this autonomy was incompatible with the hierarchical religious organization of the Church. More recently, threats to the freedom of science have come most often from hierarchical political organizations, notably in Nazi Germany and in Soviet Russia. The advance of science is hampered where scientific work is not judged by the canons of scientific activity but rather wholly by the political and social necessities of the authoritarian state. All modern societies do not now provide equally favorable political conditions for science.

We have seen, in the discussion of our six themes on the social aspects of science, that the autonomy of science, like that of other social activities, is a relative and not an absolute one. Science never has been and never can be absolutely free of some control by other elements in the society, including, of course, the political element. The freedom of science is a matter of degree, a matter of specific forms throughout this book, showing their functions for the advance of science. Such an analysis will, correlatively, indicate which kinds of control are not harmful to science. We cannot set science up against all the rest of society; the task of the sociology of science is to define their most fruitful type of interconnection.

Moreover, the relationship between science and the political system may change its specific forms, although not its general requirement of relative freedom for science. Such changes require adjustment based on understanding. In American society, for instance, although a high degree of autonomy for science continues, the relations between science and the political structure have been changing, especially during the last twenty years. As science has advanced and has grown in its social effects and social usefulness, the results of its advance have become political problems. The American Government has been continuously and on a fairly large scale concerned with the political problems of science since the Depression of the 1930's. Previously such a degree of concern had been limited to periods of war, although, as we shall see, the American Government has been somewhat involved with science for quite a long time. And since World War II, more than ever before, because of the relation of science to national defense and national prosperity, science and the Government have had increasingly close connections. This change has been remarked by President Conant of Harvard, who has himself been an extremely active and powerful participant in these relations. "Members of Congress and civilian officials of the Federal Government," he says, "have become involved in intricate questions which in large part turn on judgments about scientific and engineering problems. There can be no doubt that politics and science, once quite separate activities, have become intermeshed, and at times the grinding of the gears produces strange and disturbing noises. . . ." [2] Despite these problems, however, the necessary kind of autonomy for science seems to have been preserved in this country, most fortunately not only for science but for the whole society.

This, then, is the "ideal type," the model of the system of cultural values and social structures which would provide the most favorable conditions for science and its progress. In the degree in which one finds *all* these things—the cultural values of rationality, utilitarianism, universalism, individualism, and melioristic progress; and the social structures of a highly specialized division of labor, an open-class system, and a non-authoritarian political system—in that degree science flourishes in a modern society.

NOTES

1 Talcott Parsons, *Social Science: A Basic National Resource,* Unpublished manuscript, 1949. Also, Talcott Parsons, *The Social System,* Ch. VIII, The Free Press, Glencoe, Ill., 1951.

[2] J. B. Conant, "Science and politics in the twentieth century," *Foreign Affairs*, 28 (1950), p. 189.

DISEASES OF SCIENCE *

Derek J. de Solla Price

The following essay by Derek de Solla Price, Professor of the History of Science at Yale University, has provoked much interest in the short time it has been published. The growth of science in recent years has been so rapid that it presents hitherto unexpected problems to society, not least being the survival of science itself. In the future, Professor Price argues, science itself may have to come under rational control if we are to continue to benefit from its discoveries.

. . . It must be recognized that the growth of science is something very much more active, much vaster in its problems, than any other sort of growth happening in the world today. For one thing, it has been going on for a longer time and more steadily than most other things. More important, it is growing much more rapidly than anything else. All other things in population, economics, nonscientific culture, are growing so as to double in roughly every human generation of say thirty to fifty years. Science in America is growing so as to double in only ten years—it multiplies by eight in each successive doubling of all nonscientific things in our civilization. If you care to regard it this way, the density of science in our culture is quadrupling during each generation.

Alternatively, one can say that science has been growing so rapidly that all else, by comparison, has been almost stationary. The exponential growth has been effective largely in increasing the involvement of our culture with science, rather than in contributing to any general increase in the size of both culture and science. The past three centuries have brought science from a one-in-a-million activity to a point at which the expenditure of several per cent of all our

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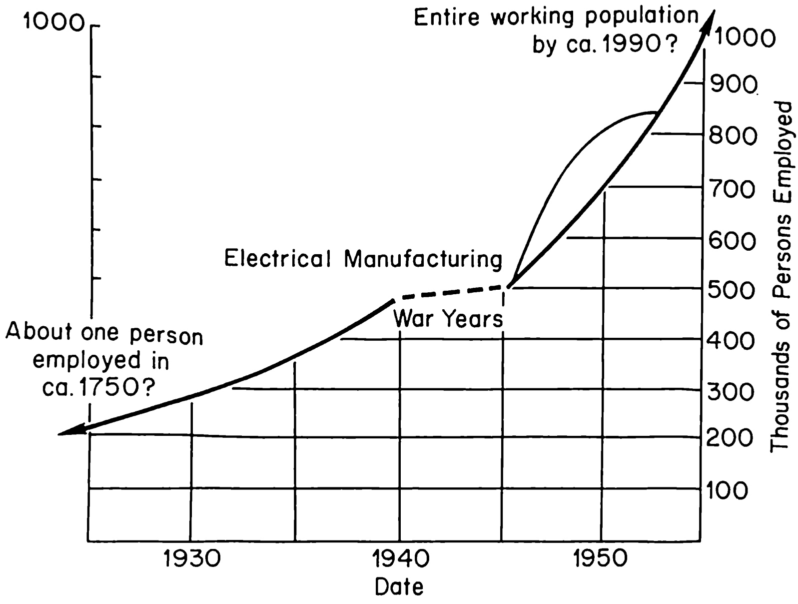
national productivity and available manpower is entailed by the general field of science and its closely associated applications.

An excellent example of such concentration is the electrical engineering industry, the technology of which is more implicitly scientific than any other. Published manpower figures show the usual exponential increase, acting as if it started with a single man *ca.* 1750 (the time of Franklin's experiments on lightning) and doubling until there were two hundred thousand people employed in 1925 and an even million by 1955. At this rate, the whole working population should be employed in this one field as early as 1990.

Returning for a moment to the history of the process rather than its statistics, it seems reasonable to identify by name this growth of science and its associated technologies from the small beginning to its present status as the largest block of national employment. It is the process we call the Industrial Revolution, if one thinks in terms of technology, or the Enlightenment, if one stresses the cognitive element.

The movement started in Europe in the mid-seventeenth century and reached large proportions measurable by thousands, rather than units, in the late eighteenth and early nineteenth centuries. Thus, our



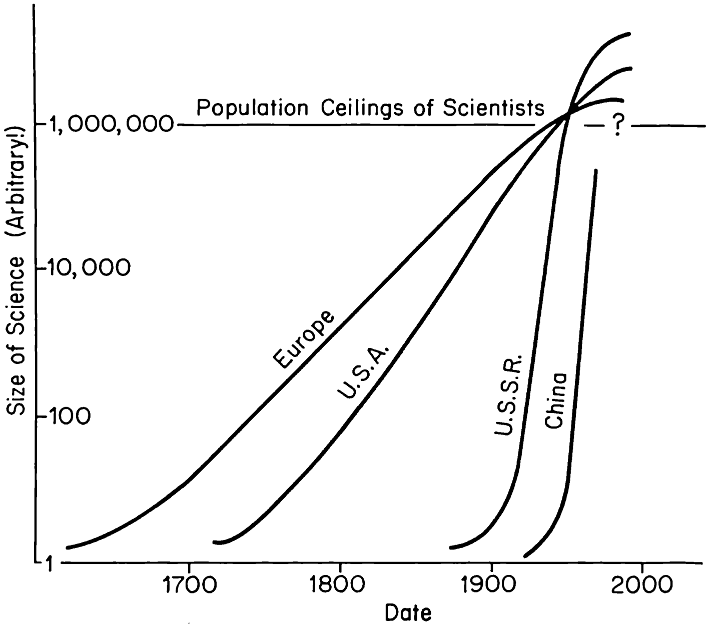
Adapted from figures published by *The Manchester Guardian* for March 20, 1956: "The Electrical Industry Today," by Dr. Willis Jackson, F. R. S.

various graphs of cumulative growth may be regarded as charting quantitatively the course of this Industrial Revolution and Enlightenment and providing a key to the various dates and phenomena associated with their progress.

It is instructive in this study to compare the growth charts of Europe with those for the United States. All the available statistics show that the United States has undergone the same sort of accurately exponential proliferation as Europe. The difference is, however, that once the United States started, it made its progress by doubling in scientific size every ten years rather than every fifteen. This was remarked upon already in 1904, in a brilliant essay in *The Education of Henry Adams* (Chapter XXXIV). The explanation of the rate difference is difficult, but the fact seems quite clear. Once the United States had, so to speak, decided to get down to a serious attempt at scientific education, research, and utilization, it was able to carry through this process at a rate of interest considerably higher than that in Europe.

A great part of the explanation is probably due not to any special and peculiar properties of the American way of life as compared with the European but merely to the fact that this country was expanding into a scientific vacuum. Furthermore, it was doing it with the help of that high state of science already reached and held as a common stock of knowledge of mankind at the date when the United States started its process. Europe had to start from the beginning, and by the eighteenth or nineteenth century it had a considerable accretion of tradition and established institutions of science and technology.

Whatever the reason, the United States continued to expand at this rate faster than Europe, and eventually it acquired an intensity of science in society that became greater than that of Europe. One can consider the scientific advancement in Russia in exactly the same way. In Czarist Russia science was not altogether inconsiderable—it partook of the general level of Europe—but after 1918 a determined effort was made to expand science. Again the statistics show that the advance has been very accurately exponential, and that the doubling time is of the order of some seven years rather than the ten of the United States and the fifteen of Europe. Again, one can attribute this in large part not to any particular excellence of the Russians or to a degree of crash-programming but rather to the fact that if they wanted to do the job at all, there was only one way of doing it, and this involved being



Schematic graph of the rise of science in various world regions. The measures, shapes of the initial portions of the curves, and the way in which the curves turn over to their respective ceilings toward the top are all merely qualitative.

able to start from a world-state of scientific knowledge that was considerably higher for them than for the start of the United States.

Lastly, we may take the case of China. Here we have an even more recent start and, consistent with the theory, we see that the statistics in that country indicate a doubling every five years. As an indication of this, it has already just become necessary and advisable to prepare running English translations of the chief Chinese scientific journals, as we have now been doing for the Russian literature over some few years. Again, rather than attribute any particular high quality to the Chinese, I would suggest that they are simply expanding into a larger scientific vacuum, starting at a higher level than any of the earlier protagonists.

The whole thing is like a gigantic handicap race in which the country that starts last must necessarily have the highest initial speed, and it seems fairly conclusive that this speed can readily be maintained —it certainly has been by America—so that the state of science must eventually reach the concentration that we see in the most highly developed countries. It is reasonable to suppose from the very universality of science and from its supranational qualities that it is much more likely for the world to reach a state of uniform development and exploitation in this direction than in many another. The handicap race of Industrial Revolutions has indeed been so well designed that it seems likely that all runners will come abreast, reaching a size of science proportional to their total populations, at much the same time, a time not too many decades distant into the future.

Because of the obvious importance of the scientific race between the United States and Russia, and that which may well occur between these countries and China, this study of the natural history of Industrial Revolutions clearly needs more attention. The modern scientific development of Japan would provide an excellent case history. The very slow beginnings in modern India might throw light on what it is that constitutes a true onset of this sort of exponential Industrial Revolution.

Having now discussed the historical origins and statistical progress of the device of the scientific paper and the profession of the scientist, we must next consider the decline and fall of these things. It is indeed apparent that the process to which we have become accustomed during the past few centuries is not a permanent feature of our world. A process of growth so much more vigorous than any population explosion or economic inflation cannot continue indefinitely but must lead to an intrinsically larger catastrophe than either of these patently apparent dangers.

To go beyond the bounds of absurdity, another couple of centuries of "normal" growth of science would give us dozens of scientists per man, woman, child, and dog of the world population. Long before that state was reached we should meet the ultimate educational crisis when nothing might be done to increase the numbers of available trained professionals in science and technology. Again, to take a reasonably safe exaggeration, if every school and college in the United States were turned to the exclusive production of physicists, ignoring all else in science and in the humanities, there would still necessarily be a manpower shortage in physics before the passage of another century.

The normal expansion of science that we have grown up with is such that it demands each year a larger place in our lives, a larger share of our resources. Eventually that demand must reach a state where it cannot be satisfied, a state where the civilization is saturated with science. This may be regarded as an ultimate end of the completed Industrial Revolution. Thus, that process takes us from the first few halting paces up to the maximum of effort. The only question that must be answered lies in the definition of that saturated state and the estimation of its arrival date.

Fortunately, the mathematical theory is again most helpful if we demand only an approximate picture and require no maze of detail. Exponential growths that become saturated and thereby slowed down to a steady level are very common in nature. We meet them in almost every field of biological growth or epidemiology. The rabbit population in Australia or the colony of fruit flies in a bottle all grow rapidly until some natural upper limit is reached. In nearly all known cases, the approach to the ceiling is rather strikingly symmetrical with the growth from the datum line. The curve of growth is a sigmoid or logistic curve, S-shaped, and even above and below its middle.

The only good historical example known to me illustrates the decline of the European Middle Ages, followed by the beginning of the Renaissance. If one makes a graph of the number of universities founded in Europe, arranged by date, the curve splits into two parts. The first part is a sigmoid curve starting at A.D. 950, growing exponentially at first but falling away rapidly by about 1450, and thereafter approaching a ceiling with equal rapidity. Added to this is a second exponential curve, doubling more rapidly than the first and acting as if it had started with a first member, a new style of university in 1450. The lesson is obvious: the old order began to die on its feet and, in doing so, allowed a quite new, renaissance concept of the university to arise.

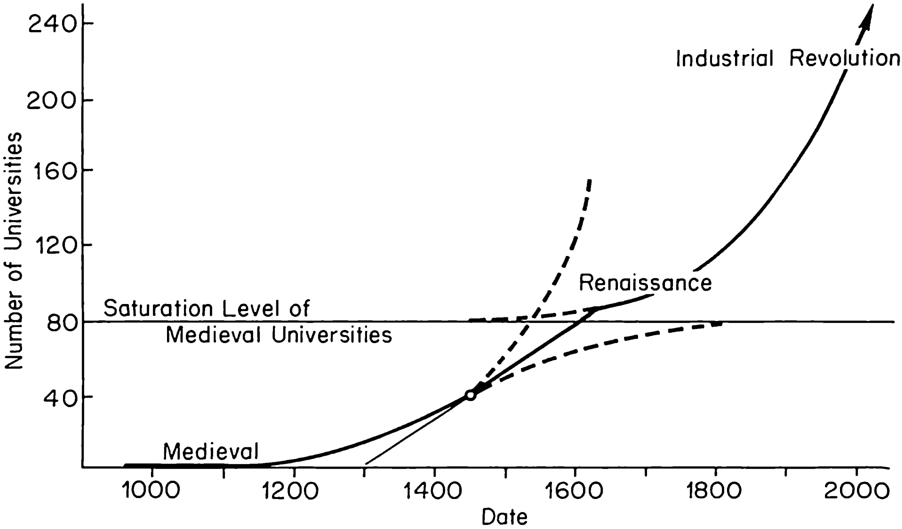
It is a property of the symmetrical sigmoid curve that its transition from small values to saturated ones is accomplished during the central portion (halfway between floor and ceiling) in a period of time corresponding to only the middle five or six doubling periods (more exactly, 5.8), independent of the exact size of the ceiling involved. Thus, the time at which the logistic curve has fallen only a few per cent below the expected, the normal exponential curve represents the onset of the process. Three doubling periods later, the deficiency is 50 per cent, the sigmoid curve reaching only half the expected height. Thereafter, the sigmoid curve becomes almost flat, while the exponential curve continues its wild increase. One must therefore say that only some three doubling periods intervene between the onset of saturation and absolute decrepitude.

For science in the United States, the accurate growth figures show that only about thirty years must elapse between the period when some few per cent of difficulty is felt and the time when that trouble has become so acute that it cannot possibly be satisfied. It seems quite apparent from the way in which we have talked, from time to time in recent years, about manpower difficulties in science that we are currently in a period in which the onset of a manpower shortage is beginning to be felt. We are already, roughly speaking, about halfway up the manpower ceiling.

The historical evidence leads one to believe that this is no incidental headache that can be cured separately by giving science an aspirin. It is just one symptom of a particularly deep-rooted disease of science. Perhaps it is more a natural process than a disease, though clearly we participants in the process are ill at ease as a result. It is essential to the nature of the case that science go through a period of vigorous growth and that there has now come a sort of post-adolescent hiatus, when the growth is done and science has its adult stature. We must not expect such growth to continue, and we must not waste time and energy in seeking too many palliatives for an incurable process. In particular, it cannot be worthwhile sacrificing all else that humanity holds dear in order to allow science to grow unchecked for only one or two more doubling periods. It would seem much more useful to employ our efforts in anticipating the requirements of the new situation in which science has become, in some way, a saturated activity of mankind, taking as high a proportion of our expenditure in brains and money as it can attain. We have not reached that stage quite yet, but it is only a very short time before we will—less than a human generation. In the meantime, we must certainly do what we can to provide the aspirin of more and better scientists, but we must also face the larger issue ahead.

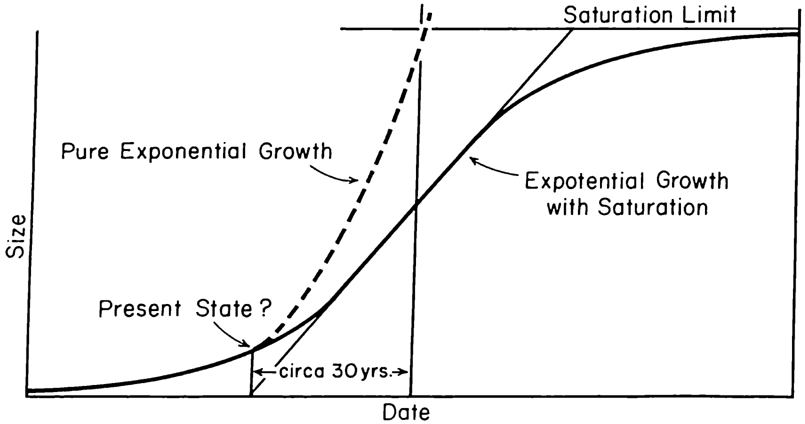
What makes it particularly exciting is that the bending of the curve toward a ceiling is happening just at that time when the handicap race of the various Industrial Revolutions has been run out and ended in a close finish. In previous decades the runners have been far apart; now they are bunched together and their speeds no longer have much effect. To think out the consequences of this, we must now examine the feeling of living in a state of saturated science.

Some of the effects are already apparent and may be amenable to historical analysis and even statistical treatment. If the cumulative expansion of science rapidly outpaces all efforts we can make to feed it with manpower, it means that more and more things will arise naturally in the life of science and require attention that cannot be



NUMBER OF UNIVERSITIES FOUNDED IN EUROPE

From the foundation at Cairo in 950 up to ca. 1460 there is pure exponential growth, doubling in about one hundred years. Thereafter saturation sets in, so that the mid-region of the sigmoid extends from 1300 to ca. 1610. Between 1460 and 1610 is a period of transition to the new form of universities, a growth that also proceeds exponentially as if it had started from unity ca. 1450 and doubling every sixty-six years. There is probably an even greater transition to yet faster growth starting at the end of the Industrial Revolution.



given. There will be too many discoveries chasing too few workers. At the highest level we must come to a situation at which there are too many breakthroughs per square head. In all previous times, for each breakthrough, such as that of X rays in 1895, there were many large groups of physicists who could attack the new problem and start to work on it. Already in our own times we have a decrease of this. In any particular area of breakthrough there are initially fewer capable specialists, and many of these are faced with the prospect of having too many interesting tidbits on their own plate to feel the need to go elsewhere, however exciting that might seem.

It may be remarked that this specialization may also be measured, and if you do it in any reasonable way, it appears to lead to the result that it, too, is doubling in every decade or so. As the amount of knowledge increases, each man must occupy a smaller and smaller segment of the research front. This, again, is not a process that can continue indefinitely; eventually a point of no return is reached at which the various disadvantages of acute specialization become too marked. Cross-fertilization of fields decreases and so thereby does the utility of the science. The more rapidly moving research front tends to leave behind such specialists, in increasing numbers, to while out their years of decline in occluded pockets.

Thus far nothing has been said about the quality of research as opposed to its quantity. This is, of course, much more difficult to determine and would repay much more serious investigation than it has ever had. Various measures are possible. One may study the growth of only important discoveries, inventions, and scientific laws, rather than all such things, important and trivial: any count of this sort immediately shows that the growth, though still exponential, possesses a doubling time that is much longer than that of the gross growth of science. The actual stature of science, in terms of its achievements, appears to double within about one generation (some thirty years) rather than in the ten years that doubles numbers of papers and numbers of scientists.[1]

In its stature, science grows much more nearly in keeping with all else in our society: size of population, economic wealth, activity in the arts. In size, however, it must undergo something like three doublings for each of these other generations. Perhaps it is not entirely wrong to see this as a consequence of the cumulative structure of science. If it grows like a pile of stones or bricks, then the pile keeps the same pyramidal shape. Its height measures the stature of science and its attainment; in this it grows at the same general rate as our culture at large. However, to make the pyramid twice as high, its volume must be multiplied by eight, the cube of two. It must undergo three doublings for every doubling of the height. The number of bricks of scientific knowledge increases as the cube of the reach of that knowledge.

Even if this is only a most approximate law, based on rather tenuous hypotheses and measurements, it nevertheless constitutes a powerful law of diminishing returns in the world of science. This finding may be easily strengthened by an analysis of the distribution in quality of scientific men. It has been proposed, on the basis of statistical investigations of the number of times that various papers were used by other people, that an inverse square law of goodness holds here as it did for productivity. For every single paper of the first order of importance there are four of secondary quality, nine of the third class, and so on. Much of the same result is obtained if one regards the spread in the scientific population as similar to that as the upper tail of a normal distribution curve of some sort of intelligence quotient.

However you do it, it seems inevitable that to increase the general number of scientists you must cut off a larger section of the tail, rather than increase the thickness of the same section of tail. Probably it follows that to double the population of workers in the few highest categories, there must be added some eight times their number of lesser individuals. At a certain point it becomes rather futile to worry about improving the standard of the low-grade men, since it is unlikely that one can tamper very much with a distribution curve that seems much the same now as it was in the seventeenth century, much the same in America as in Europe or as in Russia. Minor differences in quality of training there might be, but to work on the research front of modern science demands a high minimum of excellence.

Thus science in an age of saturation must begin to look rather different from its accustomed state. I believe it is without question that the occurrence of such a change must produce effects at least as disturbing to our way of life as an economic depression. For one thing, any slackening of the research pace of pure science must be reflected quite rapidly in our advancing technology, and thereby in our economic state.[2] It is difficult to say just what form this effect might take. Clearly there is no direct, one-to-one relationship of pure science to technology. Even if there were declared a sudden moratorium on pure scientific research, or (what is more plausible) an embargo on growth that allowed all such work to continue but without the habitual 6 per cent yearly increase in manpower, there would still be enough of a corpus of knowledge to provide for technological applications for several generations to come. As Robert Oppenheimer has expressed it, "We need new knowledge like we need a hole in the head."

There is, however, a snag in the argument as expressed above, for in the past the expansion of science and of technology have proceeded hand in hand, and it has been only the sorry task of the historian to point out examples where the one or the other has taken the leading role—an evaluation in most cases that has been revised back and forth several times each decade. I suspect, because of this intimate relationship, that although technology might be left with a great bulk of pure science waiting to be applied, any decrease in the acceleration of science will prove an unaccustomed barrier to industry, and that the flow of new ideas into industry will in some indeterminate way suffer and drop spectacularly. We are now geared to an improvement of technology at a rate of some 6 to 7 per cent per annum, and a decline in this must affect all our lives. Then, again, if manpower is chronically to be in short supply in the world of science, it will follow that *what* we do is much more important than *how much* we do it.

It follows also that the good scientist will be increasingly in demand and in power, since it must become ever more apparent that it is he who holds the purse strings of civilization in the era we have entered. Indeed, if it were not for the well-established reluctance of scientists to enter the political arena, one might boldly predict that the philosophers are about to become kings—or presidents at least.

In a saturated state of science there will be evident need to decide, either by decree or by default, which jobs shall be done and which shall be left open—remembering always that an ever increasing number of possible breakthroughs must be left unexploited. It is most doubtful whether this can be best done by considering merely the utility to society of the job in itself. In the history of science, it is notorious that practical application has often grown out of purely scientific advance; seldom has pure research arisen from a practical application by any direct means. I would be cautious here, for there are too many violent views in such areas, and the truth is certainly no unmixed extreme. But even so, it would be foolhardy to direct all medical research to work on cancer, or all physicists to work on missiles and atomic power.

If such fields are rich and important at the moment, it is evident that they have not always been so, that they will probably appear in a different light a few decades hence. In this future state, we might perchance depend on fields that are currently being starved through diversion of the funds elsewhere. If at any time in the future we wish to change, even if the demand is great, we might have already committed our resources in such a way that they cannot be converted to the new projects. Not only is science changing more and more rapidly; it is entering a completely new state.

In this new state, our civilization will rise or fall according to the tactics and strategy of our application of our scientific efforts. It is anarchical to decide such issues by merely letting ourselves be ruled by the loudest voices. It may or may not be worthwhile to support missile research to the hilt, but no man can make such a decision without considering the possibility that this work will ruin the chances of half a dozen other fields for an entire generation. In a condition in which so much of our scientific research is supported by military contracts and federal projects, it seems no man's business to consider the possible damage which could come in our new saturated state.

If the supply of research cannot simply be allowed to follow the ephemeral demand, it seems also that we can no longer take the word of the scientists on the job. Their evaluation of the importance of their own research must also be unreliable, for they must support their own needs; even in the most ideal situation they can look only at neighboring parts of the research front, for it is not their own business to see the whole picture. Quite apart from the fact that we have no national scientific policy, it is difficult to see any ground on which such a policy might be based. It is difficult to take advice from either the promoters of special jobs or from the scientists themselves, for their interests might well be opposed, might well be irrelevant, to the needs of the nation as a whole.

The trouble seems to be that it is no man's business to understand the general patterns and reactions of science as the economist understands the business world. Given some knowledge of economics, a national business policy can be formulated, decrees can be promulgated, recessions have some chance of being controlled, the electorate can be educated. I do not know, indeed, whether one might in fact understand the crises of modern science so well as to have the power to do anything about them. I must, however, suggest that the petty illnesses of science—its super-abundance of literature, its manpower shortages, its increasing specialization, its tendency to deteriorate in quality—all these things are but symptoms of a general disease. That disease is partly understood by the historian, and might be understood better if it were any man's professional province to do so. Even if we could not control the crisis that is almost upon us, there would at least be some satisfaction in understanding what was hitting us.

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[1] It is difficult to be precise about this law: so far, I feel, one may have only reasonable certainty that the stature of science, however one defines it, grows some two or three times more slowly than any measure of gross size. One need not argue about the exact size of the constant involved. What is particularly impressive is that the cost of science, in terms of expenditure in money and national income, grows much faster than the gross size. Indeed, Strong and Benfey suggest (*Journal of Chemical Education*, 37, 1960, p. 29) that United States research and development costs double every six years, whereas the persons listed in *American Men of Science* double only in twelve years. Thus it would seem that the cost goes up as the square of the number of men working, and the number of men increases as the square or cube of their effectiveness in increasing the stature of science. We have therefore a fourth or sixth power law of rapidly diminishing returns. To proceed with rocketry at ten times the present effectiveness would cost say ten thousand or perhaps a million times as much money! To return to the measurement of the stature of science, it may be noted that on the basis of such subjective lists of "important" discoveries as those of L. Darmstaedter and of P. Sorokin, the evidence seems to agree that there was quite normal exponential growth, doubling in about 120 years for all the period up to about 1660, and then again normal growth doubling every thirty years from that time to the present day.

[2] For such an analysis of the role of research in economic growth, see Raymond H. Ewell, in *Chemical and Engineering News*, 33, No. 29 (July 18, 1955) pp. 2980–5. Ewell makes a good case for the growth rate of individual industries and the gross national product both being directly proportional to the growth rate of expenditure on research and development. In detail, some 10 per cent increase in the cost of science is needed to produce the national economic growth rate of 3 per cent; that is, the scientific budget seems to increase as the cube of the general economic index.

SCIENTIFIC AND HUMANISTIC KNOWLEDGE IN THE GROWTH OF CIVILIZATION *

Karl W. Deutsch

The problem of science and values in our civilization has become an acute one. While values without knowledge leads to irresponsible action, the converse is without meaning if not suicidal. Professor Deutsch reminds us that our values spring not from science but from other sources, and that they are as necessary to science as to the humanities.

Some Problems of Science and Values

With Tolstoi and Aldous Huxley, and to a lesser extent even Swift and Wells, the focus of interest shifts from the aesthetic to the ethical aspects of science. Science itself depends for its life on the prior acceptance of certain fundamental values, such as the value of curiosity and learning, the value of truth, the value of sharing knowledge with others, the value of respect for facts, and the value of remembering the vastness of the universe in comparison with the finite knowledge of men at any particular moment. Historically, such values have been held by outstanding scientists. One thinks of P. W. Bridgman's well-known dictum that—"in the face of the fact, the scientist has a humility almost religious"; or of Newton's description of his own work as the play of a child with pebbles on the shores of the ocean of knowledge, or his reference to the sharing of knowledge with others by describing his own achievements as being due to his having stood "on the shoulders of giants." Beyond such evidence, it could perhaps be shown that the cumulative work of science could not go on if any of the values just listed were rejected.

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As science rests on certain values, so do almost all values depend on knowledge, and thus to some extent in turn on science, if they are to proceed from the realm of words to that of action. This implies a circular chain of causation or a feedback process, as do many processes of social and cultural development. To act morally is in one sense the opposite of acting blindly. It is acting in the presumed knowledge of what in fact it is that we are doing. Almost every significant action of this kind implies serious assumptions in some field of science. To love one's neighbor requires at the very least that we find out where and who our neighbor is. If we are to respond to his needs we must first ascertain what his needs are and what action in fact is likely to be helpful to him. To feed the hungry requires first of all the ability to distinguish food from poison, as well as the ability to provide food or produce food when needed. The same principles apply, of course, to clothing the naked or healing the sick. Indeed, it can be said that perhaps no action can be evaluated as good or bad without some knowledge or surmise about its consequences. If we evaluate an action as good on the basis of our mere surmise of the good will of its doer, therefore, we may find ourselves forced to assume that such subjective good will—as in the Kantian Imperative—must include by implication also the will to gain and apply the best available knowledge of the probable consequences of the action chosen. The duty to have good intentions, in other words, is meaningless without the duty to try to know the facts and try to foresee correctly the consequences of one's deeds, and it is this latter duty which may distinguish in practice the responsible from the irresponsible statesman, or the well-intentioned doctor from the well-intentioned quack.[1]

Attempts at hermetic separations of science from values are thus bound to fail. Science without at least some values would come to a dead stop; ethics without at least some exact and verifiable knowledge would be condemned to impotence or become an engine of destruction. Much of the anxious discussion of international politics between statesmen and atomic scientists, or between the so-called schools of "idealism" and "realism" among political writers, hinges upon the discrepancy between the strength of the moral convictions involved and the poverty of reliable knowledge of the probable consequences of the proposed courses of action.[2]

The relationship of science and values thus implies a double question: the mutual interrelation of science and the general values of a civilization; and the relationship of a specific state of scientific knowledge to the pursuit of specific purposes or policies. The first of these problems, the general relationship of science and values, and thus to some extent of truth and goodness, leads us close to the heart of every civilization within which it is examined. If conceived as mutually incompatible, science and values may frustrate or destroy each other, dragging their civilization towards stagnation or decline. As a mutually productive and creative partnership, science and values may succeed in strengthening each other's powers in a self-enhancing pattern of growth, rendering their civilization increasingly open and able to learn from the hopes and dreams of the individuals within it, as well as from the universe around it.

This general vision of a mutually beneficial partnership becomes increasingly difficult to retain, however, as we proceed from the consideration of the growth of civilization on the grand scale to the effect of the timing of particular discoveries or innovations upon specific policies at specific times and places. Would it have been better for mankind if Einstein's principle of relativity, or Chadwick's discovery of the neutron, or Hahn's work on uranium fission had all come ten years later than they did, and no atom bomb had been available to drop on Hiroshima? Perhaps the most useful consideration in the face of questions such as these might be to realize the impossibility of foreseeing the ultimate consequences of even the smallest scientific or technological advance, as well as the inexhaustibility of most or all of the great contributions. Benjamin Franklin's answer to the question "What is the use of a scientific discovery?" consisted in asking the counter-question "What is the use of a baby?" Just as it seems impossible to foretell the eventual good a child may do, so it is impossible to foretell what evil he may do, and our whole attitude to children is in a sense based upon the bet that the good they do will far outweigh the evil. In civilized countries we have long ago abandoned the discussion which sometimes still echoes in mythology, whether a certain child should have been killed at birth in order to forestall the harm he did in adult life. Rather we have come to center our attention on providing a family and an environment for him in which love will outweigh hate, and in which his opportunity for free and friendly growth will be the best.

If there is merit in Benjamin Franklin's argument, we might similarly decide to bet on the potential goodness rather than on the potential evil of knowledge, and concentrate on providing a human and social environment for science in which its constructive possibilities are likely to be realized. It is possible, of course, to imagine extreme situations for some times and places in which the short-term potentialities for destruction might seem so great in the case of a particular invention or discovery, and the prevailing political régime might seem so unlikely to avoid its suicidal misuse, that a policy of temporarily restricting, delaying, or withholding such knowledge might appear as the least of several likely evils for the time being. Even granting all these assumptions, however, such a policy of fear of knowledge would have to be viewed as extremely transitory and exceptional in any modern technological civilization that is to continue to advance or indeed to survive. A civilization so prone to commit suicide that it could be saved only by concealing from it the means of its own destruction would not endure for long. Rather, for the long run and for most conditions that are likely to occur, we might do better to adopt the opposite assumption: that any modern civilization that is to endure will have to learn how to live with its new knowledge of its vast means of destruction. . . .

Growth and Motivation

Throughout this discussion we may seem to have stressed the cognitive rather than the normative aspects of both art and science. Yet we are persuaded that the knowledge of that which ought to be cannot be divorced from the knowledge of that which is, and that the effort to know what is good cannot be separated from knowing what is real. For we call "good" that which is not self-destructive in its consequences, either for the mind of the doer, or for the smaller or larger community in which he lives. In its crudest terms, to be good means not to commit suicide, and not even to commit it by instalments. In religious language, it means to seek life everlasting, to love God—the vast reality around us—and to love our neighbor as ourselves. In the language of Kant's philosophy, it means so to act that the motive of our actions could be a general law of nature, or so to act that the principle of our action could be a general principle of human society; or finally, so to act that no human being shall be treated by our action as a mere instrument but as an end withal.

Each of these descriptions of good or ethical behavior implies the necessity of a lively and responsible concern for the consequences of one's actions. A man's attempted estimate of the probable consequences of his own act helps us distinguish the good intention of a doctor (even if his operation should not succeed) from the callous recklessness of the quack (even if by some great good luck his patient should survive). Good will, in Kant's sense, thus necessarily implies the will to know as far as possible the probable consequences of one's acts.

Yet if we know what is good (in the sense of knowing what behavior would probably have good consequences), we may not necessarily be motivated to do it. There are minds that can be aimed but are not loaded: on their triggering to action nothing follows but a click. Science has no direct influence on human motivation. It depends on the existence of human motives which it does not create, although its results may help to strengthen them. The humanities, on the contrary, present us with configurations of symbols and experiences that may have profound effects on the configuration of our motives. What is in science at best a by-product, the effect on the social, moral, and spiritual motives of human beings, can become—though it need not become—one of the central concerns of the humanities.

To be sure, the humanities can try to avoid this challenge. In the short novel *Tonio Kröger*, the young Thomas Mann suggested that the artist must be like an actor or like a dead man, for he must portray emotions he must not share. "Sincerity" and "good intentions" were thus left to the bumbling efforts of well-meaning amateurs. But the more mature Thomas Mann brought his great novel *The Magic Mountain* to the opposite conclusion; his hero risks his life, in dubious battle, in order to share the fate, the hopes, and the good intentions of his fellows. The inescapable burden of cognition, the inescapable responsibility for making one's battles less dubious in value, and one's acts and intentions less precarious in outcome—none of these should deflect our attention from the core and foundation of both scientific and humanistic work: the deep and self-renewing motivation of men and women to compassionate, merciful, and competent action.

NOTES

[1] Some of the problems are discussed in Margaret Mead, ed., *Cultural Patterns and Technical Change* (UNESCO, 1953).

[2] For instances of discussions of this kind, see the *Bulletin of Atomic Scientists, passim;* George F. Kennan, *American Diplomacy, 1900–1950* (Chicago: University of Chicago Press, 1951); Thomas I. Cook and Malcolm Moos, "The American Idea of International Interest," *American Political Science Review,* XLVII, No. 1 (March, 1953), 28–44.

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