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Source: *American Journal of Sociology*, Vol. 47, No. 4 (Jan., 1942), pp. 544-562
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/2769053
Accessed: 20-09-2017 18:53 UTC

THE SOCIOLOGICAL ROOTS OF SCIENCE

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ABSTRACT

In the period from 1300 to 1600 three strata of intellectual activity must be distinguished: university scholars, humanists, and artisans. Both university scholars and humanists were rationally trained. Their methods, however, were determined by their professional conditions and differed substantially from the methods of science. Both professors and humanistic literati distinguished liberal from mechanical arts and despised manual labor, experimentation, and dissection. Craftsmen were the pioneers of causal thinking in this period. Certain groups of superior manual laborers (artist-engineers, surgeons, the makers of nautical and musical instruments, surveyors, navigators, gunners) experimented, dissected, and used quantitative methods. The measuring instruments of the navigators, surveyors, and gunners were the forerunners of the later physical instruments. The craftsmen, however, lacked methodical intellectual training. Thus the two components of the scientific method were separated by a social barrier: logical training was reserved for upper-class scholars; experimentation, causal interest, and quantitative method were left to more or less plebeian artisans. Science was born when, with the progress of technology, the experimental method eventually overcame the social prejudice against manual labor and was adopted by rationally trained scholars. This was accomplished about 1600 (Gilbert, Galileo, Bacon). At the same time the scholastic method of disputation and the humanistic ideal of individual glory were superseded by the ideals of control of nature and advancement of learning through scientific co-operation. In a somewhat different way, sociologically, modern astronomy developed. The whole process was imbedded in the advance of early capitalistic society, which weakened collective-mindedness, magical thinking, and belief in authority and which furthered worldly, causal, rational, and quantitative thinking.

Were there many separate cultures in which science has developed and others in which it is lacking, the question about the origin of science would generally be recognized as a sociological one and could be answered by singling out the common traits of the scientific in contrast to the nonscientific cultures. Historical reality, unfortunately, is different, for fully developed science appears once only, namely, in modern Western civilization. It is this fact that obscures our problem. We are only too inclined to consider ourselves and our own civilization as the natural peak of human evolution. From this presumption the belief originates that man simply became more and more intelligent until one day a few great investigators and pioneers appeared and produced science as the last stage of a one-line intellectual ascent. Thus it is not realized that human thinking has developed in many and divergent ways—among which one is the scien-

[1] This article outlines a study undertaken with the help of grants from the Committee in Aid of Displaced Foreign Scholars, the Rockefeller Foundation, and the Social Science Research Council.

tific. One forgets how amazing it is that science arose at all and especially in a certain period and under special sociological conditions.

It is not impossible, however, to study the emergence of modern science as a sociological process. Since this emergence took place in the period of early European capitalism, we shall have to review that period from the end of the Middle Ages until 1600. Certain stages of the scientific spirit, however, developed in other cultures too, e.g., in classical antiquity and, to a lesser degree, in some oriental civilizations and in the Arabic culture of the Middle Ages. Moreover, the scientific and half-scientific cultures are not independent of each other. In modern Europe the beginnings of science, particularly, have been greatly influenced by the achievements of ancient mathematicians and astronomers and medieval Arabic physicians. We shall, however, discuss not this influence but the sociological conditions which made it possible. We can, necessarily, give but a sketchy and greatly simplified analysis of this topic here. All details and much of the evidence must be left to a more extensive exposition at another place.

I

Human society has not often changed so fundamentally as it did with the transition from feudalism to early capitalism. These changes are generally known. Even in a very brief exposition of the problem, however, we must mention some of them, since they form necessary conditions for the rise of science.

1. The emergence of early capitalism is connected with a change in both the setting and the bearers of culture. In the feudal society of the Middle Ages the castles of knights and rural monasteries were the centers of culture. In early capitalism culture was centered in towns. The spirit of science is worldly and not military. Obviously, therefore, it could not develop among clergymen and knights but only among townspeople.

2. The end of the Middle Ages was a period of rapidly progressing technology and technological inventions. Machines began to be used both in production of goods and in warfare. On the one hand, this set tasks for mechanics and chemistry, and, on the other, it furthered causal thinking, and, in general, weakened magical thinking.

3. In medieval society the individual was bound to the traditions of the group to which he unalterably belonged. In early capitalism economic success depended on the spirit of enterprise of the individual. In early feudalism economic competition was unknown. When it started among the craftsmen and tradesmen of the late medieval towns, their guilds tried to check it. But competition proved stronger than the guilds. It dissolved the organizations and destroyed the collective-mindedness of the Middle Ages. The merchant or craftsman of early capitalism who worked in the same way as his fathers had was outstripped by less conservative competitors. The individualism of the new society is a presupposition of scientific thinking. The scientist, too, relies, in the last resort, only on his own eyes and his own brain and is supposed to make himself independent of belief in authorities. Without criticism there is no science. The critical scientific spirit (which is entirely unknown to all societies without economic competition) is the most powerful explosive human society ever has produced. If the critical spirit expanded to the whole field of thinking and acting it would lead to anarchism and social disintegration. In ordinary life this is prevented by social instincts and social necessities. In science itself the individualistic tendencies are counterbalanced by scientific co-operation. This, however, will be discussed later.

4. Feudal society was ruled by tradition and custom, whereas early capitalism proceeded rationally. It calculated and measured, introduced bookkeeping, and used machines. The rise of economic rationality furthered development of rational scientific methods. The emergence of the quantitative method, which is virtually nonexistent in medieval theories, cannot be separated from the counting and calculating spirit of capitalistic economy. The first literary exposition of the technique of double-entry bookkeeping is contained in the best textbook on mathematics of the fifteenth century, Luca Pacioli's *Summa de arithmetica* (Venice, 1494); the first application of double-entry bookkeeping to the problems of public finances and administration was made in the collected mathematical works of Simon Stevin, the pioneer of scientific mechanics (*Hypomnemata mathematica* [Leyden, 1608]), and a paper of Copernicus on monetary reform (*Monetae cudendae ratio* [composed in 1552]) is

among the earliest investigations of coinage. This cannot be mere coincidence.

The development of the most rational of sciences, mathematics, is particularly closely linked with the advance of rationality in technology and economy. The modern sign of mathematical equality was first used in an arithmetical textbook of Recorde that is dedicated to the "governors and the reste of the Companio of Venturers into Moscovia" with the wish for "continualle increase of commoditie by their travell" (*The Wetstone of Witte* [London, 1557]). Decimal fractions were first introduced in a mathematical pamphlet of Stevin that begins with the words: "To all astronomers, surveyors, measurers of tapestry, barrels and other things, to all mintmasters and merchants good luck!" (*De thiende* [Leyden, 1585]). Apart from infusions of Pythagorean and Platonic metaphysics, the mathematical writings of the fifteenth and sixteenth centuries first deal in detail with problems of commercial arithmetic and, second, with the technological needs of military engineers, surveyors, architects, and artisans. The geometrical and arithmetical treatises of Piero de' Franceschi, Luca Pacioli, and Tartaglia in Italy, Recorde and Leonard Digges in England, Dürer and Stifel in Germany, are cases in point. Classical mathematical tradition (Euclid, Archimedes, Apollonius, Diophantus) could be revived in the sixteenth century because the new society had grown to demand calculation and measurement.

Even rationalization of public administration and law had its counterpart in scientific ideas. The loose state of feudalism with its vague traditional law was gradually superseded by absolute monarchies with central sovereignty and rational statute law. This political and juridical change promoted the emergence of the idea that all physical processes are governed by rational natural laws established by God. This, however, did not occur before the seventeenth century (Descartes, Huyghens, Boyle).[2]

II

We have mentioned a few general characteristics of early capitalistic society which form necessary conditions for the rise of the scien-

[2] Cf. Edgar Zilsel, "The Genesis of the Concept of Physical Law," *Philosophical Review*, LI (1942).

tific spirit. In order to understand this development sociologically, we have to distinguish three strata of intellectual activity in the period from 1300 to 1600: the universities, humanism, and labor.

At the universities theology and scholasticism still predominated. The university scholars were trained to think rationally but exercised the methods of scholastic rationalism which differ basically from the rational methods of a developed economy. Tradesmen are interested in reckoning; craftsmen and engineers in rational rules of operation, in rational investigation of causes, in rational physical laws. Schoolteachers, on the other hand, take an interest in rational distinction and classifications. The old sentence, "bene docet qui bene distinguit," is as correct as it is sociologically significant. Schoolteaching, by its sociological conditions, produces a specific kind of rationality, which appears in similar forms wherever old priests, intrusted with the task of instructing priest candidates, rationalize vague and contradictory mythological traditions of the past. Brahmans in India, Buddhist theologians in Japan, Arabic and Catholic medieval scholastics conform in their methods to an astonishing degree. Jewish Talmudists proceeded in the same way, though, not being priests by profession, they dealt with ritual and canon law rather than with proper theological questions. This school rationality has developed to a monstrous degree in Brahmanic Sankhya-philosophy (sankhya means "enumeration").

As a rule the specific scholastic methods are preserved when theologians, in the course of social development, apply themselves to secular subject matters. Thus in Indian literature Brahmans who had entered the service of princes discussed politics and erotics by meticulously distinguishing and enumerating the various possibilities of political and sexual life (Kautilya, Vatsyayana).[3] In a somewhat analogous way the medieval scholastics and the European university scholars before 1600 indulged in subtle distinctions, enumerations, and disputations. Bound to authorities, they favored quotation and uttered their opinions for the most part in the form of commentaries and compilations. After the thirteenth century mundane subject matters were treated by scholars, too, and, as an exception,

[3] Cf. M. Winternitz, *Geschichte der indischen Literatur* (Leipzig, 1920), III, 509 ff., 536 ff.

even experience was referred to by some of them. But when the Schoolmen were at all concerned with secular events they did not, as a rule, investigate causes and, never, physical laws. They endeavored rather to explain the ends and meanings of the phenomena. Obviously, the occult qualities and Aristotelian substantial forms of scholasticism are but rationalizations of prescientific, magic, and animistic teleology. Thus till the middle of the sixteenth century the universities were scarcely influenced by the development of contemporary technology and by humanism. Their spirit was still substantially medieval. It seems to be a general sociological phenomenon that rigidly organized schools are able to offer considerable resistance to social changes of the external world.[4]

The first representatives of secular learning appeared in the fourteenth century in Italian cities. They were not scientists but secretaries and officials of municipalities, princes, and the pope looking up with envy to the political and cultural achievements of the classical past. These learned officials who chiefly had to conduct the foreign affairs of their employers became the fathers of humanism. Their aims derive from the conditions of their profession. The more erudite and polished their writings, the more eloquent their speeches, the more prestige redounded to their employers and the more fame to themselves. They therefore chiefly strove after perfection of style and accumulation of classical knowledge. In the following centuries the Italian humanists lost in large part their official connections. Many became free literati, dependent on princes, noblemen, and bankers as patrons. Others were engaged as instructors to the sons of princes, and several got academic chairs and taught Latin and Greek at universities. Their aims remained unchanged, and their pride of memory and learning, their passion for fame, even increased. They acknowledged certain ancient writers as patterns of style and

[4] Pierre Duhem has brought into prominence the fourteenth-century Ockhamists of the university of Paris (Buridan, Oresme, and others) and has attempted to vindicate for them scientific priority to Copernicus and Galileo. Though knowledge of late scholasticism has been greatly furthered by Duhem's investigation of the Paris Schoolmen, he has considerably overrated their "anticipations" of modern physical and astronomical ideas. He singles out the scarce and rather extrinsic conformities with modern natural science and omits the abundance of differences. Duhem's opinion has been uncritically adopted by many followers.

were bound to these secular authorities almost as strictly as the theologians were to their religious ones. Though humanism also proceeded rationally, its methods were as different from scholastic as from modern scientific rationality. Humanism developed the methods of scientific philology, but neglected causal research and was ignorant of physical laws and quantitative investigation. Altogether it was considerably more interested in words than in things, more in literary forms than in contents. Humanism spread over all parts of western and central Europe. Though the professional conditions and intellectual aims of the humanists outside Italy were somewhat more complex, on the whole their methods were the same.[5]

The university scholars and the humanistic literati of the Renaissance were exceedingly proud of their social rank. Both disdained uneducated people. They avoided the vernacular and wrote and spoke Latin only. Further, they were attached to the upper classes, sharing the social prejudices of the nobility and the rich merchants and bankers and despising manual labor. Both, therefore, adopted the ancient distinction between liberal and mechanical arts: only professions which do not require manual work were considered by them, their patrons, and their public to be worthy of well-bred men.

The social antithesis of mechanical and liberal arts, of hands and tongue, influenced all intellectual and professional activity in the Renaissance. The university-trained medical doctors contented themselves more or less with commenting on the medical writings of antiquity; the surgeons who did manual work such as operating and dissecting belonged with the barbers and had a social position similar

[5] It seems to be a rather general sociological phenomenon that, where there are professional public officials, secular learning first appears in the form of humanism. In China also after the dissolution of feudalism in the period of Confucius a group of literati officials developed who were chiefly interested in perfection of style and who acknowledged certain ancient writings as literary models. In the following period admission to civil service was made dependent on examinations regarding literary style and knowledge of antiquity. In China even calligraphy belonged to the formal requirements of higher education, Chinese writing characters being more complicated than European ones. Secular scribes, proud of their profession and learning and bound to ancient models, can be found also in ancient Egypt and the neo-Parthian empire. In classical antiquity there was an abundance of rhetors, grammarians, philologists, and philosophers rather resembling the humanistic literati of the Renaissance. Yet lack of professional civil servants in the republican period prevented development of a perfect correspondence.

to that of midwives. Literati were much more highly esteemed than were artists. In the fourteenth century the latter were not separated from whitewashers and stone-dressers and, like all craftsmen, were organized in guilds. They gradually became detached from handicraft, until a separation was effected in Italy about the end of the sixteenth century. In the period of Leonardo da Vinci (about 1500) this had not yet been accomplished. This fact appears rather distinctly in the writings of contemporary artists who over and over again discussed the question as to whether painting and sculpture belong with liberal or mechanical arts. In these discussions the painters usually stressed their relations to learning (painting needs perspective and geometry) in order to gain social esteem. Technological inventors and geographical discoverers, being craftsmen and seamen, were hardly mentioned by the humanistic literati. The great majority of the humanists did not report on them at all. If they mentioned them, they did so in an exceedingly careless and inaccurate way. From the present point of view the culture of the Renaissance owes its most important achievements to the artists, the inventors, and the discoverers. Yet these men entirely recede into the background in the literature of the period.[6]

Beneath both the university scholars and the humanistic literati the artisans, the mariners, shipbuilders, carpenters, foundrymen, and miners worked in silence on the advance of technology and modern society. They had invented the mariner's compass and guns; they constructed paper mills, wire mills, and stamping mills; they created blast furnaces and in the sixteenth century introduced machines into mining. Having outgrown the constraints of guild tradition and being stimulated to inventions by economic competition, they were, no doubt, the real pioneers of empirical observation, experimentation, and causal research. They were uneducated, probably often illiterate,[7] and, perhaps for that reason, today we do not

[6] On the prestige of the literati, artists, inventors, and discoverers cf. Edgar Zilsel, *Die Entstehung des Geniebegriffes: Ein Beitrag zur Ideengeschichte der Antike und des Fruehkapitalismus* (Tübingen, 1926), pp. 130–75, and 176 f. (statistical evidence).

[7] Cf. the statistical data on population and number of school children in the chronicle of Giovanni Villani (X, 162 [fourteenth century, Florence]) and J. W. Adamson, "The Extent of Literacy in England in the 15th and 16th Centuries," *Library*, X (4th ser., 1930), 167.

even know their names. Among them were a few groups which needed more knowledge for their work than their colleagues did and, therefore, got a better education. Among these superior craftsmen the artists are most important. There were no sharp divisions between painters, sculptors, goldsmiths, and architects; but very often the same artist worked in several fields, since, on the whole, division of labor had developed only slightly in the Renaissance. Following from this a remarkable professional group arose during the fifteenth century. The men we have in mind may be called artist-engineers, for not only did they paint pictures, cast statues, and build cathedrals, but they also constructed lifting engines, canals and sluices, guns and fortresses. They invented new pigments, detected the geometrical laws of perspective, and constructed new measuring tools for engineering and gunnery. The first of them is Brunelleschi (1377–1446), the constructor of the cupola of the cathedral of Florence. Among his followers were Ghiberti (1377–1466), Leone Battista Alberti (1407–72), Leonardo da Vinci (1492–1519), and Vanoccio Biringucci (d. 1538) whose booklet on metallurgy is one of the first chemical treatises free of alchemistic superstition. One of the last of them is Benvenuto Cellini (1500–1571), who was a goldsmith and sculptor and also worked as military engineer of Florence. The German painter and engraver Albrecht Dürer, who wrote treatises on descriptive geometry and fortifications (1525 and 1527), belongs to this group. Many of the artist-engineers wrote—in the vernacular and for their colleagues—diaries and papers on their achievements. For the most part these papers circulated as manuscripts only. The artist-engineers got their education as apprentices in the workshops of their masters. Only Alberti had a humanistic education.

The surgeons belonged to a second group of superior artisans. Some Italian surgeons had contacts with artists, resulting from the fact that painting needs anatomical knowledge. The artificers of musical instruments were related to the artist-engineers. Cellini's father, for example, was an instrument-maker, and he himself was appointed as a pope's court musician for a time. In the fifteenth and sixteenth centuries the forerunners of the modern piano were constructed by the representatives of this third group. The makers of nautical and astronomical instruments and of distance meters for surveying and gunnery formed a fourth group. They made compasses and astrolabes, cross-staffs, and quadrants and invented the declinometer and inclinometer in the sixteenth century. Their measuring-instruments are the forerunners of the modern physical apparatus. Some of these men were retired navigators or gunners.[8] The surveyors and the navigators, finally, were also considered as representatives of the mechanical arts. They and the map-makers are more important for the development of measurement and observation than of experimentation.

These superior craftsmen made contacts with learned astronomers, medical doctors, and humanists. They were told by their learned friends of Archimedes, Euclid, and Vitruvius; their inventive spirit, however, originated in their own professional work. The surgeons and some artists dissected, the surveyors and navigators measured, the artist-engineers and instrument-makers were perfectly used to experimentation and measurement, and their quantitative thumb rules are the forerunners of the physical laws of modern science. The occult qualities and substantial forms of the scholastics, the verbosity of the humanists were of no use to them. All these superior artisans had already developed considerable theoretical knowledge in the fields of mechanics, acoustics, chemistry, metallurgy, descriptive geometry, and anatomy. But, since they had not learned how to proceed systematically, their achievements form a collection of isolated discoveries. Leonardo, for example, deals sometimes quite wrongly with mechanical problems which, as his diaries reveal, he himself had solved correctly years before. The superior craftsmen, therefore, cannot be called scientists themselves, but they were the immediate predecessors of science. Of course, they were not regarded as respectable scholars by contemporary public opinion. The two components of scientific method were still separated before 1600—methodical training of intellect was preserved for upper-class learned people, for university scholars, and for humanists; experimentation and observation were left to more or less plebeian workers.

The separation of liberal and mechanical arts manifested itself

[8] Cf., e.g., the *Oxford Dictionary of National Biography* on the English instrument-makers, Humfrey Cole (d. 1580), William Bourne (d. 1583), and Robert Norman.

clearly in the literature of the period. Before 1550 respectable scholars did not care for the achievements of the nascent new world around them and wrote in Latin. On the other hand, after the end of the fifteenth century, a literature published by "mechanics" in Spanish, Portuguese, Italian, English, French, Dutch, and German had developed. It included numerous short treatises on navigation, vernacular mathematical textbooks, and dialogues dealing with commercial, technological, and gunnery problems (e.g., Étienne de la Roche, Tartaglia, Dürer, Ympyn), and various vernacular booklets on metallurgy, fortification, bookkeeping, descriptive geometry, compass-making, etc. In addition there were the unprinted but widely circulated papers of the Italian artist-engineers. These books were diligently read by the colleagues of their authors and by merchants. Many of these books, especially those on navigation, were frequently reprinted, but as a rule they were disregarded by respectable scholars. As long as this separation persisted, as long as scholars did not think of using the disdained methods of manual workers, science in the modern meaning of the word was impossible. About 1550, however, with the advance of technology, a few learned authors began to be interested in the mechanical arts, which had become economically so important, and composed Latin and vernacular works on the geographical discoveries, navigation and cartography, mining and metallurgy, surveying, mechanics, and gunnery.[9] Eventually the social barrier between the two components of the scientific

[9] Peter Martyr (1511, 1530), Peter Apian (1529), Gemma Phrysius (1530), Orontius Finaeus (1532), Nunes (1537, 1546, 1566), George Agricola (1544, 1556), Pedro de Medina (1545), Ramusio (1550), Leonard Digges (1556, 1571, 1579), Mercator (1569, 1578, 1594), Benedetti (1575), Guido Ubaldo (1577), Hakluyt (1589), Thomas Hood (1590, 1592, 1596, 1598), Robert Hues (1594), Edward Wright (1599), and others. The high percentage of English authors is striking. They seem to have been interested in the mechanical arts earlier than Continental writers (cf. Francis R. Johnson, *Astronomical Thought in Renaissance England* [Baltimore, 1937]). On the other hand, in the same period a few "mechanics" rose to a scientific level in their activities and their writings: the Dutch engraver and map-maker Abraham Ortelius (1527–98), who became geographer to Philip II of Spain and a scientific cartographer; the French barber-surgeon Ambroise Paré (1510–90), who became surgeon to Henry II of France and the founder of modern scientific surgery; the cashier and bookkeeper of the municipalities of Antwerp and Bruges, Simon Stevin (1548–1620), who became technological and mathematical instructor and adviser to Maurice of Nassau, quartermaster-general of Holland, and one of the founders of modern scientific mechanics.

method broke down, and the methods of the superior craftsmen were adopted by academically trained scholars: real science was born. This was achieved about 1600 with William Gilbert (1544–1603), Galileo (1564–1642), and Francis Bacon (1561–1626).

William Gilbert, physician to Queen Elizabeth, published the first printed book composed by an academically trained scholar which was based entirely on laboratory experiment and his own observation (*De magnete* [1600]). Gilbert used and invented physical instruments but neither employed mathematics nor investigated physical laws. Like a modern experimentalist he is critically-minded. Aristotelism, belief in authority, and humanistic verbosity were vehemently attacked by him. His scientific method derives from foundrymen, miners, and navigators with whom he had personal contacts. His experimental devices and many other details were taken over from a vernacular booklet of the compass-maker Robert Norman, a retired mariner (1581).[10]

Galileo's relations to technology, military engineering, and the artist-engineers are often underrated. When he studied medicine at the University of Pisa in the eighties of the sixteenth century, mathematics was not taught there. He studied mathematics privately with Ostilio Ricci, who had been a teacher at the Accademia del Disegno in Florence, a school founded about twenty years earlier for young artists and artist-engineers. Its founder was the painter Vasari. Both the foundation of this school (1562) and the origin of Galileo's mathematical education show how engineering and its methods gradually rose from the workshops of craftsmen and eventually penetrated the field of academic instruction. As a young professor at Padua (1592–1610), Galileo lectured at the university on mathematics and astronomy and privately on mechanics and engineering. At this time he established workrooms in his house, where craftsmen were his assistants. This was the first "university" laboratory in history. He started his research with studies on pumps, on the regulation of rivers, and on the construction of fortresses. His first printed publication (1606) described a measuring tool for military purposes which he had invented. All his life he liked to visit dockyards

[10] Cf. Edgar Zilsel, "The Origin of William Gilbert's Scientific Method," *Journal o the History of Ideas*, II (1941), 1–32.

and to talk with the workmen. In his chief work of 1638, the *Discorsi*, the setting of the dialogue is the Arsenal of Venice. His greatest achievement—the detection of the law of falling bodies, published in the *Discorsi*—developed from a problem of contemporary gunnery, as he himself declared.[11] The shape of the curve of projection had often been discussed by the gunners of the period. Tartaglia had not been able to answer the question correctly. Galileo, after having dealt with the problem for forty years, found the solution by combining craftsman-like experimentation and measurement with learned mathematical analysis. The different social origin of the two components of his method—which became the method of modern science—is obvious in the *Discorsi*, since he gives the mathematical deductions in Latin and discusses the experiments in Italian. After 1610 Galileo gave up writing Latin treatises and addressed himself to nonscholars. His greatest works, consequently, are written completely or partially in Italian. A few vernacular poets were among his literary favorites. Even his literary taste reveals his predilection for the plain people. His aversion to the spirit and methods of the contemporary professors and humanists is frequently expressed in his treatises and letters.

The same opposition to both humanism and scholasticism can be found in the works of Francis Bacon. No scholar before him had attacked belief in authority and imitation of antiquity so passionately. Bacon was enthusiastic about the great navigators, the inventors, and the craftsmen of his period; their achievements, and only theirs, are set by him as models for scholars. The common belief that it is "a kind of dishonor to descend to inquiry upon matters mechanical"[12] seems "childish" to him. Induction, which is proclaimed by him as the new method of science, obviously is the method of just those manual laborers. He died from a cold which he caught when stuffing a chicken with snow. This incident also reveals how much he defied all customs of contemporary scholarship. An experiment of this kind was in his period considered worthy rather of a cook or knacker than of a former lord chancellor of England. Bacon, however, did not make any important discovery in the field

[11] Letter to Marsili (November 11, 1632), *Opere* (ed. nazionale), XIV, 386.

[12] *Novum Organum*, I, aph. 120.

of natural science, and his writings abound with humanistic rhetoric, scholastic survivals, and scientific mistakes. He is the first writer in the history of mankind, however, to realize fully the basic importance of methodical scientific research for the advancement of human civilization.

Bacon's real contribution to the development of science appears when he is confronted with the humanists. The humanists did not live on the returns from their writings but were dependent economically on bankers, noblemen, and princes. There was a kind of symbiosis between them and their patrons. The humanist received his living from his patron and, in return, made his patron famous by his writings. Of course, the more impressive the writings of the humanist, the more famous he became. Individual fame, therefore, was the professional ideal of the humanistic literati. They often called themselves "dispensers of glory" and quite openly declared fame to be the motive of their own and every intellectual activity. Bacon, on the contrary, was opposed to the ideal of individual glory. He substituted two new aims: "control of nature" by means of science and "advancement of learning." Progress instead of fame means the substitution of a personal ideal by an objective one. In his *Nova Atlantis* Bacon depicted an ideal state in which technological and scientific progress is reached by planned co-operation of scientists, each of whom uses and continues the investigations of his predecessors and fellow-workers. These scientists are the rulers of the New Atlantis. They form a staff of public officials organized in nine groups according to the principle of division of labor. Bacon's ideal of scientific co-operation obviously originated in the ranks of manufacturers and artisans. On the one hand, early capitalistic manual workers were quite accustomed to use the experience of their colleagues and predecessors, as is stressed by Bacon himself and occasionally mentioned by Galileo. On the other hand, division of labor had advanced in contemporary society and in the economy as a whole.

Essential to modern science is the idea that scientists must co-operate in order to bring about the progress of civilization. Neither disputing scholastics nor literati, greedy of glory, are scientists. Bacon's idea is substantially new and occurs neither in antiquity nor in the Renaissance. Somewhat similar ideas were pointed out in the same period by Campanella and, occasionally, by Stevin and Descartes. As is generally known, Bacon's *Nova Atlantis* greatly influenced the foundation of learned societies. In 1654 the Royal Society was founded in London, in 1663 the Académie française in Paris; in 1664 the *Proceedings* of the Royal Society appeared for the first time. Since this period co-operation of scientists in scientific periodicals, societies, institutes, and organizations has steadily advanced.

On the whole, the rise of the methods of the manual workers to the ranks of academically trained scholars at the end of the sixteenth century is the decisive event in the genesis of science. The upper stratum could contribute logical training, learning, and theoretical interest; the lower stratum added causal spirit, experimentation, measurement, quantitative rules of operation, disregard of school authority, and objective co-operation.[13]

III

The indicated explanation of the development of science obviously is incomplete. Money economy and co-existent strata of skilled artisans and secular scholars are frequent phenomena in history. Why, nevertheless, did science not develop more frequently? A comparison with classical antiquity can fill at least one gap in our explanation.

Classical culture produced achievements in literature, art, and philosophy which are in no way inferior to modern ones. It produced outstanding and numerous historiographers, philologists, and grammarians. Ancient rhetoric is superior to its modern counterpart both in refinement and in the number of representatives. Ancient achievements are considerable in the fields of theoretical astronomy and

[13] The development of modern astronomy took place in a somewhat different way. After the days of the Babylonian priests, the links connecting astronomy with priesthood, calendar-arranging, and religious feasts had never been quite interrupted. Astronomy, therefore, was linked with the idea of celestial sublimity and always belonged to the free arts. As a consequence Pythagorean and nonmechanical animistic ideas are conspicuous in Copernicus and Kepler. Practical astronomy, on the other hand, was linked with navigation, which was interested in exact star positions and measuring instruments. In the period of Newton the metaphysical and astrological spirit was definitely overcome in scientific astronomy.

mathematics, limited in the biological field, and poor in the physical sciences. Only three physical laws were correctly known to the ancient scholars: the principles of the lever and of Archimedes and the optical law of reflection. In the field of technology one difference is most striking: machines were used in antiquity in warfare, for juggleries, and for toys but were not employed in the production of goods. On the whole, ancient culture was borne by a rather small upper class living on their rents. Earning money by professional labor was always rather looked down upon in the circles determining ancient public opinion. Manual work was even less appreciated. In the same manner as in the Renaissance, painters and sculptors gradually detached from handicraft and slowly rose to social esteem. Yet their prestige never equaled that of writers and rhetors, and even in the period of Plutarch and Lucianus the greatest sculptors of antiquity would be attacked as manual workers and wage-earners. Compared with poets and philosophers, artists were rarely mentioned in literature, and engineers and technological inventors virtually never. The latter presumably (very little is known of them) were superior artisans or emancipated slaves working as foremen. In antiquity rough manual work was done by slaves.

As far as our problem is concerned, this is the decisive difference between classical and early capitalistic society. Machinery and science cannot develop in a civilization based on slave labor. Slaves generally are unskilled and cannot be intrusted with handling complex devices. Moreover, slave labor seems to be cheap enough to make introduction of machines superfluous. On the other hand, slavery makes the social contempt for manual work so strong that it cannot be overcome by the educated. For this reason ancient intellectual development could not overcome the barrier between tongue and hand. In antiquity only the least prejudiced among the scholars ventured to experiment and to dissect. Very few scholars, such as Hippocrates and his followers, Democritus, and Archimedes, investigated in the manner of modern experimental and causal science, and even Archimedes considered it necessary to apologize for constructing battering-machines. All these facts and correlations have already been pointed out several times.

It may be said that science could fully develop in modern Western civilization because European early capitalism was based on free labor. In early capitalistic society there were very few slaves, and they were not used in production but were luxury gifts in the possession of princes. Evidently lack of slave labor is a necessary but not a sufficient condition for the emergence of science. No doubt further necessary conditions would be found if early capitalistic society were compared with Chinese civilization. In China, slave labor was not predominant, and money economy had existed since about 500 B.C. Also there were in China, on the one hand, highly skilled artisans and, on the other, scholar-officials, approximately corresponding to the European humanists. Yet causal, experimental, and quantitative science not bound to authorities did not arise. Why this did not happen is as little explained as why capitalism did not develop in China.

The rise of science is usually studied by historians who are primarily interested in the temporal succession of the scientific discoveries. Yet the genesis of science can be studied also as a sociological phenomenon. The occupations of the scientific authors and of their predecessors can be ascertained. The sociological function of these occupations and their professional ideals can be analyzed. The temporal succession can be interrupted and relevant sociological groups can be compared to analogous groups in other periods and other civilizations—the medieval scholastics with Indian priest-scholars, the Renaissance humanists with Chinese mandarins, the Renaissance artisans and artists with their colleagues in classical antiquity. Since, in the sociology of culture, experiments are not feasible, comparison of analogous phenomena is virtually the only way of finding and verifying causal explanations. It is strange how rarely investigations of this kind are made. As the complex intellectual constructs are usually studied historically only, so sociological research for the most part restricts itself to comparatively elementary phenomena. Yet there is no reason why the most important and interesting intellectual phenomena should not be investigated sociologically and causally.

INSTITUTE OF SOCIAL RESEARCH
NEW YORK

BIBLIOGRAPHICAL NOTE

The sociological analysis of nascent science must be based primarily on the writings of the scientific authors from 1400 to 1650. The material is very extensive but must be used in its entirety. For the relations of science to technology, commerce, military engineering, and instrument-making the following authors are especially important: Luca Pacioli, Tartaglia, the English mathematicians Recorde and Leonard and Thomas Digges, Stevin, William Gilbert, Galileo, and Francis Bacon. Often (e.g., in Guido Ubaldo) valuable sociological material is contained in the prefaces and dedications. The vernacular writings of the craftsmen, instrument-makers, and navigators are important. The following authors may be mentioned: Ghiberti (*Commentarii* [*ca.* 1450]), Piero de'Franceschi (*De prospectiva pingendi* [1484]), Leonardo, Alberti, Biringuccio (*Pirotechnia* [*ca.* 1540]), Dürer (*Underweysung der Messung* [1525], *Befestigung der stett, schloss und flecken* [1527]), William Bourne (*Inventions or Devises* [1578], *On the properties and qualities of glasses*, in I. O. Halliwell (ed.), *Rara mathematica*), Robert Norman (*The newe attractive* [1581]), William Borough (*Discourse of the variation of the compass* [1581]), Palissy (*Récepte véritable* [1560], *Discours admirable* [1580]). Strictly speaking, the works also of Tartaglia, Stevin, and Ambroise Paré belong to this group. Also many textbooks on mathematics and treatises on navigation were composed by nonscholars.

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