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Aspects of the Professionalization of Science

THE INSTITUTIONALIZATION and professionalization of science that has taken place in the past century has justly been called the second scientific revolution. Seen historically, this revolution has resulted from the fusion of rapidly maturing scientific disciplines with western organizational and administrative techniques, enabling large numbers of scientists with varying interests and abilities to be marshaled for massive projects of research and development. In the process, the separation which once existed between science and technology has been narrowed and bridged, and science has come to exert a major influence upon economic growth. At the same time, the very methods and objectives of science have been deeply affected, for they are no longer primarily private or personal but have a large social component.

The first scientific revolution introduced to the western world a new way of looking at phenomena, with an emphasis upon accuracy of observation, quantification of data, verification of results, and useful prediction. Although many of these values were shared by those who took part in the technological revolution which laid the foundation for the modern industrial age, the scientist and the engineer or mechanic proceeded along parallel rather than convergent paths. Only when the full utility of science became evident to capitalistic promoters or state officials were the two streams of development combined.

The consequences of this mutual interaction upon society in general have been both numerous and momentous, and they need not be described here. With regard to science and its practitioners, however, two results should be recalled. First, because of the way in which advances in scientific knowledge can be transmuted into tangible and even awesome results, the professional scientist today enjoys financial support and public recognition in high degree.

Since World War II, he has gained considerable influence with regard to the formulation and execution of public policy and a strong voice in the councils of many large industrial corporations. Second, as science and technology are drawn into ever closer cooperation, the chief types of institution in which professional scientists are employed—colleges or universities and industrial or governmental laboratories—share an increasing number of common characteristics. The researcher who is employed in the one may be engaged in work which is quite similar to that performed by a scientist in the other.

This situation differs greatly from that which prevailed only a century ago, for professionalized science manifested itself first in educational institutions and only somewhat later in private and state laboratories devoted to increasing agricultural or industrial productivity and efficiency. Before 1900, most professional scientists were teachers in universities, technical institutes and trade or secondary schools. Relatively few were employed in industry, with the major exceptions of the dyestuffs and electrical fields. In some countries, such as Great Britain and France, there was an aristocratic prejudice against abandoning the quest of pure truth for the pursuit of financial gain, stemming in part from a tradition of scientific research conducted by amateur gentlemen of private means. For the scientist unlucky enough to have to work for a living, the main alternative to teaching was government service. Even here jobs were difficult to secure, there being few if any government research laboratories and only a handful of technical or supervisory jobs available in arsenals, mines, observatories, public health services, geodetic surveys or civil engineering projects.

If many scientists looked with disfavor upon industrial employment, manufacturers often had serious misgivings about establishing close relationships with scientists. Although some academically trained researchers had well-developed business instincts—for example, Charles Martin Hall and William Henry Perkin—the entrepreneur typically thought of the scientist as a person too committed to abstract scholarship to be directly useful in a profit-seeking enterprise. In addition, the tradition of trade secrecy which existed in many factories clashed with the desire of scholars to disseminate the results of their research. To those who managed industries based upon empirical methods and employed artisans imbued with a craft viewpoint, the scientist might also appear as a menace to established routine and job classification, and hence as a potentially antagonizing influence with regard to the working force.

Finally, and perhaps most important, academic science had only begun to be translated into practical terms so clear cut and potentially lucrative as to entice business interest. More often the nonacademic inventor, with largely commercial motives, managed to produce significant innovations by making empirical use of scientific principles already fifty or more years old. In the absence of theoretically trained industrial scientists ever ready to pounce upon new academic discoveries, the lag between initial advance and ultimate application thus remained large.

Although most technical and industrial innovation was still in the hands of empirical inventors during the late nineteenth century, several of the academic sciences, such as thermodynamics, electromagnetism, optics, chemistry, bacteriology and biology, had now reached a point of development at which the existence of large and well-classified accumulations of data permitted the formulation of highly useful and comprehensive theoretical systems which could be exploited in a commercial and technological sense. As the practical and pecuniary potential of these new syntheses and advances came more clearly into view, particularly in the dyestuffs and electrical industries, the purse strings of private donors and governmental bodies were opened to finance improved scientific education and to establish well-equipped research laboratories.

These developments ultimately produced more and more trained researchers and a steadily growing number of positions for which they could be hired. There was an initial tendency for most scientifically trained university graduates to be brought back into expanding programs of technical education, but the proportion gradually decreased as those who entered industry demonstrated their value—indeed their indispensibility—to formerly skeptical entrepreneurs. Although the timing and rate of scientific professionalization differed from one industrial nation to another, similar trends were taking place throughout the world. The nearly complete displacement of the amateur scientist by his teaching colleague was ultimately followed by a sharp growth in the number of industrial researchers, who displaced the empirical inventors and who in time came to outnumber the academic scientists.[1]

It is of interest to note that as science became professionalized late in the nineteenth century, the division between basic and applied research became institutionalized. Basic science remained almost exclusively the province of the university. In industrial laboratories, entrepreneurs seized upon scientific processes or techniques which could lead swiftly to profitable results. Product testing, for example, was one of the first ways in which science demonstrated its utility to the manufacturer, thanks to the proliferation of ingenious analytical instruments and to the need of the industrialist for precise measurements and specifications in the volume production of goods made with interchangeable parts or standardized ingredients. The application of science to improving efficiency, eliminating unnecessary steps, conserving raw materials and finding various uses for by-products was also of great benefit to entrepreneurs who were trying to cut costs in the face of competition and declining price levels. By serving in such capacities, scientists could bring quick and tangible returns at a relatively small financial outlay to a great number of industries.

Positions involving mere testing and analysis had a tendency to become stultifyingly routine, and they were consequently unattractive to scientists with first rate capabilities. Other circumstances also created nagging annoyances which many professionally trained men found difficult to tolerate. Although eager to derive profit from science, most industrialists wanted to keep research budgets as low as possible. In addition, as we have previously mentioned, they wanted to guard against antagonizing craft-oriented employees, to preserve factory stability and to keep knowledge of certain processes from leaking out to potential competitors. It was not uncommon, therefore, for an industrial scientist to be consigned to a poorly equipped back room or an out-of-the-way corner of a plant and strictly forbidden to trespass in other departments. In some cases, manufacturers found it possible to train raw factory hands to make simple tests and routine analyses, and so to limit their scientific staffs to a few professionals who could be counted on absolutely to preserve trade secrets.[2] To such entrepreneurs, it seemed cheaper and less dangerous to buy patents from the outside than to run the risk and expense of large and continuous development programs of their own.

Because of this cautious approach, much applied research had to be done outside the factory if it was to be carried on at all. One type of institution which sprang up partly in response to this situation was the independent commercial research laboratory, typified by the firm of Arthur D. Little, founded in 1886. In addition, certain universities and academic scholars, while retaining a primary emphasis upon basic inquiries, became engaged in applied research. Such faculty members as Michael Pupin of Columbia University, who devised a loading coil for the effective transmission of impulses in long-range telephony, found it profitable to invent as well as to theorize.[3] Professors more and more frequently entered into formal consulting arrangements with manufacturing concerns, served as expert witnesses in patent litigation, and steered their students into research projects having a bearing upon industrial problems. In time, universities themselves established institutional ties with industry, thanks to the efforts of such men as Robert Kennedy Duncan, a chemistry professor at the University of Kansas. Believing that the research chemist was placed in a stultifying position in industrial employment, where he was likely to do one routine testing operation over and over, Duncan came to the conclusion that most manufacturers had neither the background nor the education to direct the efforts of scientists. The solution was for the scientist to remain at the university and to have the industrialist come there for help. Duncan persuaded academic officials at Kansas to start a program of industrial fellowships under which graduate students could work at the university on projects suggested and financed by businessmen. He later moved to the University of Pittsburgh, where his ideas were implemented at the Mellon Institute. By 1917, the industrial fellowship idea, which had also been put into effect in Germany in the late nineteenth century, had spread to universities and technical institutes in such countries as Canada, Great Britain, Australia, Finland and Japan.[4]

Although their ideas about the undesirability of placing scientists in factories thus led to the establishment of an important type of institution, the industry-oriented university research institute, such men as Duncan failed to realize that the condition of the scientist in a nonacademic habitat did not necessarily have to be as stultifying as they depicted it. The small manufacturing concern, highly competitive and cost-conscious, continued to rely on routine testing, and farmed more demanding projects out to other institutions. On the other hand, a large industrial organization, heavily capitalized and holding a dominant market position under cartel or oligopoly conditions, could provide a reasonably satisfying atmosphere for the creative researcher under wise and percipient executive leadership. This type of situation, lacking in most manufacturing plants, eventually came to exist in such fields as the dyestuffs and electrical industries. In Germany, for example, such firms as Meister, Lucius & Brüning and the Badische Anilin- und Soda-Fabrik established genuine research organizations clearly distinguishable from the one-or two-man operation or from the mere testing division.[5] Similar developments occurred in the German and English electrical industries as new leaders succeeded men like Werner Siemens, who had retarded his company's development by rejecting the alternating current system as unworkable, by insisting that the laboratory work mainly on his own pet problems, and by manifesting an excessive skepticism toward academic theoreticians.

In the United States, where the emergence of large chemical empires was delayed until World War I, the electrical industry had the distinction of bringing the first really modern industrial laboratory into existence. After Thomas A. Edison had relinquished control of the electrical enterprise associated with his name, and Charles Coffin became the dominant figure in the newly constituted General Electric Corporation, conditions were brought about under which such academically trained theorists as Charles P. Steinmetz could make outstanding careers within the confines of an industrial organization. Furthermore, the exploitation of alternating current phenomena and the need to develop highly complex equipment for electrical transmission and use made it absolutely necessary for the industry to hire the best men available for research work. In 1900, the General Electric Laboratory was established at Schenectady, New York, under the direction of Willis R. Whitney, and an outstanding program of experimentation and creative effort was begun. Other large American firms followed in short order as Du Pont established explosives laboratories in Wilmington, Delaware and Gibbstown, New Jersey; Eastman-Kodak set up a research program in photography under C. E. K. Mees at Rochester, New York; and A.T.&T. began a centralized laboratory in New York City through the efforts of John J. Carty.

At such laboratories, both in Europe and in the United States, research work was placed under the direction of men who were purely scientific in their interests and who managed to introduce much of the university atmosphere into the industrial situation. Under such scientists as Carl Duisberg in Germany and Whitney in the United States, academically trained personnel were encouraged to undertake basic research projects, to participate in conferences modeled upon university seminars, to maintain regular contact with academic consultants, to write papers for professional journals and to attend scholarly meetings. In laboratories of this type advanced research was clearly distinguished from development; extensive libraries were provided; up-to-date equipment was made available;

auxiliary specialists were hired; and well-organized programs of recruitment and training were undertaken. With respect to the last, industrial laboratories began to exert effective influence upon the curricula of universities and technical institutes to obtain the types of staff members which they desired.

Thus, through the efforts of men like Duncan on the one hand and various industrial laboratory officials on the other, and despite obvious differences in motivation, manufacturing organizations and universities were brought into a mutually helpful relationship. Basic science remained the chief concern of academic institutions, but many industrial researchers, like Irving Langmuir of General Electric, carried on fundamental explorations of their own. Applied research and development predominated in the activities of industrial laboratories, but some university scholars and students also worked on projects of this type. In either case a direct link was provided between science and technology as basic discoveries were systematically explored at the higher theoretical levels of applied research, adapted to industrial use in pilot plants and ultimately exploited commercially. In addition to serving as the source of most of the fundamental achievements and a considerable number of practical applications, the university also provided virtually all of the scientific personnel of the laboratories, thus heavily influencing the quality of work which would be done in such institutions. In turn, industrial organizations endowed professorial chairs; financed university facilities; established scholarships, prizes and loan funds; and placed representatives on academic boards of trustees. As a result of this interaction, educational and business institutions have become parts of a continuous spectrum of scientific effort.

The closeness of this relationship has given rise to a number of problems affecting professional scientists in both the academic and the industrial fields. Fears are frequently expressed that the capacity of the university to advance human knowledge is being impaired by an undue emphasis upon explorations in areas of immediate usefulness. While some educational institutions have not hesitated to seek financial reward by engaging in applied research on toothpaste additives, rodent killers and vitamin compounds,[6] others have made earnest attempts to confine the efforts of faculty scientists to investigations of a fundamental nature. This, however, is not easy at a time in which more and more research at the academic level is being financed through grants from private organizations or governmental agencies. There is no doubt that many basic projects are promoted in this manner, because of an awareness on the part of the donors that serendipity does occur and that fundamental advances can lead to profitable results in unsuspected fields. But the faculty member often still finds that support for research comes more readily if, when writing his proposal, he is careful to stress the potential practical applications of his ideas and does not propose to explore too far beyond the existing frontiers of science. Thus a subtle pressure is detected which could, if unchecked, pose a danger to progress in fundamental science itself.

Of more immediate concern to many professional scientists, however, is the problem of fitting vocational hopes and aspirations into the spectrum of effort just described. One of the most powerful traditions established in the first scientific revolution was that of the liberty of the scientist to pursue truth according to the dictates of his curiosity. Because professionalized science first arose in an academic environment, this tradition was reinforced by the university scholar's desire for academic freedom in teaching and research. In addition, as a member of a profession the scientist shares with physicians, lawyers and other practitioners of specialized knowledge the desire to have the standards of his work set by his peers rather than by persons outside his field of competence. In short, he wants to be a colleague, not an employee. In this respect, the vocational choices available to him frequently fall short of his desires.

Although the sociologist Simon Marcson in particular has emphasized the degree to which the university scientist of today is caught up in an employee situation,[7] the professional who desires a maximum of freedom in his work and an opportunity to expand basic knowledge will normally realize these objectives more readily in an academic position than in an industrial laboratory. Evidence gathered by such analysts as Francis Bello indicates that the most gifted and creative young scientists usually gravitate to the universities or toward employment with a very few business corporations noted for allowing great latitude to talented research personnel. As enrollments burgeon at institutions of higher learning, more and more academic positions are becoming available; but it is obvious that colleges and universities could not begin to absorb all the products of graduate training, let alone the great numbers of those gaining baccalaureate degrees. Most scientists, therefore, must find employment in other fields. The popular stereotype of the scientist as a professor thus fails to correspond with actual facts; he is more likely to be a researcher with an industrial firm or a government agency. If one wishes to understand the pressures and problems facing the typical scientist today, one must examine the conditions that exist in such types of environment.

Despite the many ways in which the industrial laboratory has come to resemble the university situation in the twentieth century, the fledgling researcher may find in this area of employment conditions for which he may have been unprepared by his academic training. Like any business organization, the manufacturing firm exists in order to make a profitable return on the investments of its owners, and its research efforts are conducted with this aim in mind. As we have seen, this does not mean that fundamental research will be entirely neglected in favor of applied science, nor that the industrial laboratory will be subjected to the same type of efficiency analysis and cost accounting used with relation to other departments of the same firm. It does mean that the thought of ultimate application can never be wholly absent from any investigator's mind, and that some basic advances will have to lead to profitable results if a basic research program is to justify itself to management. It also means that most of the scientists employed in industry and most of the money spent for their work will be channeled into the development of applications for known principles.

The industrial research director is well aware that he is dealing with scarce and highly trained manpower imbued with professional aspirations and unwilling to settle for the status of the ordinary employee. As a man of scientific training himself, he also knows that genuine creativity can exist only in a situation in which staff members are impelled by inner drives, rather than by exterior compulsion, to penetrate the unknown. Top management too is normally cognizant of such special circumstances, so that in most large firms the laboratory divisions are allowed a considerable degree of autonomy. However, there are limits beyond which permissiveness cannot go, as the engineer C. E. Skinner learned in the period 1916–1921, when as first director of the Westinghouse research organization, he tried to establish a laboratory in which there was little or no pressure for immediate or short-range results.[8] Far more percipient in this regard was Willis Whitney of General Electric, who unfailingly gave priority to requests for help on problems submitted by the corporation's various operating departments.[9] The successful research director therefore plays a mediatory role between the executive echelons of the company and the professional staff, reconciling if possible the expectations and viewpoints of each.

This far from easy task is usually accomplished by a slow process of suggestion and persuasion through which the scientist is motivated in a relatively indirect manner to carry out company wishes. In at least one contemporary American laboratory analyzed by Simon Marcson, the similarities between university and industrial practices are stressed when a prospective staff member is interviewed. Most new Ph.D.'s in science are imbued at least in some measure with the academic ideal of pursuing knowledge for its own sake, and they express a desire to be permitted to do some independent research. Industrial recruiters are usually able to assure the prospective staff member that facilities and some time are available for this purpose, and they point with pride to the laboratory's discoveries, the articles published in professional journals and the national reputation of the staff. But after the young man is hired, a period of adjustment occurs in which he gradually becomes aware of what his superiors expect of him. In Marcson's words, "Acculturation takes place as the laboratory and the recruited scientist learn from each other and change each other." However, "The laboratory . . . effects more changes in the scientist than vice versa."[10] The very atmosphere and work load of most industrial laboratories are so strongly weighted toward obtaining prompt, tangible and profitable results that the recruit's ideal of independent, basic research is put to a severe test.

At this point the majority of the new men abandon or modify their earlier values and ambitions. They do so for a number of reasons. They may discover that the pressure of assigned projects is so great or the effort to please superiors so consuming that insufficient time is left in the 8:30 to 5:00 day to pursue individual research interests. Staying beyond 5:00 P.M., although perhaps officially encouraged by the company, is generally not practiced by the staff, and hence only the most strongly motivated will stay to work overtime on pet projects. Or, as happens frequently, the new researcher may discover that assigned research is equally taxing and fascinating, and fully as satisfying, as his thesis research had been. Incidentally, that thesis topic is likely to have been suggested by his professor. Hence at this point in his career the young scientist, his idealistic commitment to scientific self-direction notwithstanding, has possibly never initiated a research project of his own, and thus finds industrial research not so different from what he knew at the university as he might originally have thought. Further, he may discover that a considerable amount of self-reliance and ingenious initiative is required in solving assigned problems, and that his work for industry often requires greater tenacity and elegance of execution than were needed in academic research. For at the university virtually any result represents a publishable article, which is the tangible product and measure of academic productivity; but in many industrial laboratories the only acceptable result is one which works, and works simply and well enough to be commercially feasible.

In fact, many of the new staff soon become so absorbed by the challenge of rendering an idea commercially feasible that they forget all about their one-time ambition of making some great contribution to basic science. All too often we hear only of scientists leaving industry for freer research environments elsewhere, when there are probably at least as many or more who leave large laboratories to develop on their own the practical potential of ideas which they obtained while working for industry or government.

Those among the new staff who persevere in their determination to contribute to basic science can usually find some time (one fifth or more in some industrial laboratories) for this purpose; but initially they may need to work overtime on such projects if these are to move along satisfactorily. Should the results prove of interest to the company, the researcher may obtain permission to devote more, or possibly all of his time to his project. Beyond that always exists the chance of being given the support of an entire research team. If, on the other hand, such a scientist fails to convince his superiors of the commercial potential of his personal project, he may feel sufficiently restricted in his effort to quit the company for the academic world or for another research organization more favorably inclined toward his own field of interest. This, however, does not seem to happen too often. Most scientists in industry learn to live with the frustrations and opportunities of their jobs. They usually understand the business framework within which decisions concerning industrial research must be made, and they are aware of the fact that other research environments, including universities, are no less free of tensions and disadvantages.

Aside from the usually superior monetary rewards proffered by industry, many scientists find satisfactions in industrial research which may be lacking in university life. Some, who have little interest in or aptitude for teaching, may welcome freedom from lecture preparation and working with students. Others find the auxiliary services available in industrial laboratories superior to those afforded by graduate assistants and other personnel on the academic scene. Some large companies may be better able to provide expensive equipment than any but the most well-endowed educational institutions. According to at least one laboratory director, it may actually be possible for a manufacturing firm to provide a scientist having marked personality idiosyncracies with a more congenial setting than would be attainable in an academic institution, where such a person would have frequent contacts with students and be obliged to take part in committee meetings or other functions.

Here again must be emphasized the wide variety of objectives and opportunities which exist at some industrial laboratories, particularly the three hundred largest ones which together perform 80 per cent of all American industrial research. Even though the industrial laboratory can make more effective use than the universities of scientists whose talents are rather ordinary, industry is no haven for scientific mediocrity, for it must also attract highly imaginative and superior persons who are among the best that the graduate schools can offer, and retain their services if at all possible. Thus when one examines the techniques used in managing research personnel one encounters a wide variety of administrative practices, *ad hoc* relationships, written and unwritten rules of behavior and informal, but none the less real, channels of influence. The highly structured chain of command which typifies the industrial enterprise is present, but it is considerably modified in practice because of the special problems which are encountered in operating a hybrid organization staffed by specialized individuals who are both self-motivated and disciplined, professionals and employees.

It is difficult to generalize in the face of such a situation as this, but two scientists connected with the Bell Telephone Laboratories have presented a cogent analysis of three basic relationships which develop between staff members of a research department and the management under which they work.[11] At the lowest level is the *artisan-master* relationship. Here the employer knows exactly what he wants and has a concrete idea of how this can be obtained. The scientist engaged in routine testing and analysis fits into this pattern, which exists at any large laboratory and may still be the dominant type of situation prevailing in a small research department run by a highly cost-conscious company which farms out most projects of a higher order, if indeed it has any. At the next level is the *professional-client* relationship. Here the autonomy of management is abridged because those who hire the services of specialists do not really know how a given project is to be consummated, how much time it will take, how much equipment will be needed and how the results will affect the market strategy of the company. Presumably most industrial scientists with advanced credentials—master's or doctor's degrees—will fall into this category. Finally, there is the *protégé-patron* relationship similar to that which once existed between members of the nobility and artists like Michaelangelo, musicians like Haydn, and scientists like Galileo. Perhaps the earliest example of such a person in American industrial research was Charles P. Steinmetz; at a later date, Irving Langmuir filled such a role at General Electric. Working under minimal supervision, protégés may discover basic phenomena of great potential profitability and considerably enhance the growth possibilities of the corporations which employ them. They may also bring the firm great prestige, some of which can be transmuted into advertising value. Langmuir, for example, won a Nobel Prize in 1932 for his studies in the behavior of surface films. Steinmetz brought General Electric such renown that a company official once estimated his advertising value alone at $1,000,000.[12] Thus even the highest form of brilliance does not escape the commercializing tendency in the industrial situation.

The rewards for proficiency and achievement in industrial research are substantial, but often for the professionally minded scientist they are too exclusively monetary and unaccompanied by honorific titles which denote changes in status. There is a tendency in the business world to bestow new job titles only when persons are given new responsibilities or elevated to positions of increasing power, and not merely for growth in capability within the same type of work. Even when industrial scientists are put in charge of group projects, this is frequently done on an informal basis and with no titular change. This is justified by laboratory officials on two grounds: first, that research groupings are only temporary and that flexibility must be preserved if personnel are to be shifted about as the needs of the company dictate; second, that the spirit of teamwork in a laboratory may be impaired if too many distinctions are made. Plausible though these reasons may be, they fail to satisfy the status aspirations of persons whose thinking is heavily imbued with academic standards of recognition.

Cognizant of these circumstances, some industrial corporations have begun to experiment with ranking systems which demonstrate particularly well the manner in which university science departments and company laboratories are becoming more and more alike in certain respects. One leading American chemical firm, for example, has established two scales of titles—two ladders of achievement—one for scientists who remain in actual research and the other for those who go into administrative positions. The recruit is normally classed as a "Research Chemist," corresponding roughly with the grade of "Instructor" in the academic world. If he stays in research work, he may rise to "Senior Research Chemist," "Research Associate," and ultimately "Research Fellow," the pinnacle of recognition on this ladder. If on the other hand he becomes a research administrator, he advances through such grades as "Supervisor," "Senior Supervisor," and "Manager." If his executive abilities are particularly marked, he may eventually become a "Laboratory Director" or proceed into the highest managerial ranks of the company. The obvious distinction between the two ladders, of course, is that the one is almost purely honorific while the other involves formally recognized progress in power.

In order to hold its most creative researchers, the government too has found it necessary since World War II to create civil service classifications that reward the research scientist at a rate parallel and commensurate with the scientist-administrator.[13] Government, however, has found it difficult to make such changes in personnel policy as quickly as has industry, so that it has tended to lag behind in its capacity to attract and retain scientists. Despite vigorous action by the research agencies and the Civil Service to extend the salary scale, particularly at the top, to expedite hiring procedures and to maximize the researcher's freedom of action and communication, many scientists still leave or refuse government employment because they consider the salaries and the opportunities for advancement inferior to those of industry.[14] Less often than formerly, however, are they quitting because of unsympathetic management practices and red tape. Job security, superior research facilities, and fringe benefits which in former times tended to offset the disadvantages of government employment are on the whole no longer superior to what industry now offers, though they remain better than what academic institutions can manage to hold out. The fact that much governmental research is contracted out to private industry on a cost-plus-fixed-fee basis has often permitted industry to outbid government laboratories for scientific personnel, and hence has added to the government's recruitment difficulties.[15]

Yet, despite all these handicaps, the government has managed to diminish or offset them so as to increase appreciably the fraction of the nation's scientific manpower which it employs. It has been particularly successful in attracting and holding biological and social scientists, for whom there is a less desperate demand than for mathematicians and physical scientists. In mathematics, the physical sciences and engineering the government has competed effectively with industry for recent university graduates, but less successfully at higher levels. Indeed in many cases government laboratories have acted as training centers for industry, which lures away promising scientists just as they reach full productivity. When an agency loses such an individual, it often raids other government laboratories to fill the vacancy.

Clearly the point is at hand when the government must reevaluate its manpower policy and scientific priority system if it is to maintain any kind of order and balance in its research activities, particularly as it plunges deeper and deeper into the gigantic space programs now underway. Furthermore, since governmental science by its very size now vitally affects the direction of all scientific activity in the country, such a manpower policy must be conceived within the framework of a plan encompassing the whole nation's scientific endeavors. Thus far, no such plan is in the making. Vast federal research programs continue to battle each other for men and funds while all of them together compete with industry and the universities.

Such competition would be more salutary if the supply of scientists and engineers were not already scarce in relation to projects needing their services. By and large, projects involving military space research are now outbidding those oriented toward the commercial sector of the economy or toward the extension of basic knowledge. The National Aeronautics and Space Administration's own research centers and industrial subcontractors alone could easily absorb all of the 30,000 new engineers and scientists who will become available in 1963. Of the 400,000 American scientists and engineers currently engaged in research and development, 280,000 are employed in government-sponsored projects such as defense and space, while the remaining 120,000 work in industry on civilian objectives. Likewise, over 71 per cent of the $15 billion total expended in 1962 for research and development in the United States was spent by the government for military and related projects.[16] The major redeployment of our scientific manpower made possible by these enormous government appropriations has not allowed a proportionate strengthening of other sectors of the scientific front and has given rise to much concern.

During the late 1940's and the 1950's, it was often argued that, far from retarding innovation in the civilian sector of the economy, the shift toward massive military research would not only produce the necessary weapons but also simultaneously generate a flood of peace-time applications far surpassing in quantity what existing industrial laboratories could produce with purely commercial backing. We have now learned that this is not the case. Thus far, investigations with military potential in the 1940's and 1950's in fields such as radar, atomic energy and space exploration have not made as great a contribution to the gross national product, despite the vast resources devoted to their development, as a number of far more modest research programs specifically aimed at the civilian market in such areas as agriculture and polymer chemistry. The fact is that the technical adaptation of scientific principles to such civilian needs as transportation, housing, food, clothing and education is a very complicated process requiring much time and labor, and quite different in nature from the equally complicated development of modern weapons. The arms race plus the current shortage of scientific manpower often preclude the simultaneous pursuit by defense-oriented laboratories of promising civilian applications. Thus, despite the fact that our overall national research expenditures tripled between 1947 and 1960, the rate of economic growth actually dropped during that period from a fair 3.7 per cent per annum to a sluggish 3 per cent. Officials of the Department of Commerce now point to the imbalance in our research effort toward military ends as an important cause for the lackluster economic progress made by the United States in recent years, warning us that such vigorous world competitors as the Netherlands, Germany, Japan and Sweden have all been spending about 1.25 per cent of their gross national product on civilian research to our 0.80 per cent.[17]

Another imbalance in our scientific effort, aggravated by the manpower shortage and by the spiraling cost of research, is that which exists between small and big business. As we noted, of 300,000 manufacturing companies in the United States, approximately 300 perform 80 per cent of industrially sponsored research. These same 300 companies account for 60 per cent of the sales of all manufactured products and for 61 per cent of the total manufacturing employment. While these companies spend an amount equal to 2.75

per cent of their sales on research and development, the remaining small firms can afford an average of only 0.9 per cent, or about one third as much.[18] If small business is to remain vigorous, and if it is desirable to try allocating to all sectors of our economy a more or less comparable share of the nation's scientific resources, new measures must be taken. These will possibly involve increasing cooperative research by several firms or by entire industries, assisted where necessary by government, as has been done with considerable success in Europe since World War I.

To these imbalances between military and civilian research and between scientific research in big and small business must be added the imbalance existing between basic and academic research on one side and applied civilian and military research on the other. Furthermore, disparities arise between the various sciences as a consequence of some gaining public favor while others fall into neglect. Thus the magnitude of the problems facing modern science in using its limited resources wisely becomes apparent.

Until recently, the institutional structure of science was built piecemeal and haphazardly as each government agency or business corporation sought to devise, more or less empirically, that organizational pattern which it felt would best meet its immediate needs. Now, as these originally separate units have grown more interdependent scientifically, while at the same time competing more vigorously for scarce manpower, there has arisen a need on the part of each to make the most of its existing research staff, and on the part of all to coordinate their efforts for maximum overall benefit to each other and to society. Yet progress along both these lines is considerably hampered by a dearth of abundant, accurate data relating to the science of managing science, a discipline still in its infancy but which hopefully, when mature, will help to guide the formulation of scientific policy as economics now guides decision-making in the business world.

It is also highly likely that in the future, research institutions will engage the services of efficiency analysts and science management experts trained in scientific fields, to peer over the shoulders of researchers, to evaluate records and team performance and to act as consultants to scientific task forces during all phases of their research work from inception to final evaluation. They may at first be received with smirks and later with resentment by working scientists, who will declare that discovery is an unscrutable, highly personal and necessarily inefficient act; but at that point, the scientists themselves might do well to recall that the artisan and the factory foreman a half century ago accorded them a very similar reception. As the process of discovery becomes more clearly understood, it seems probable that its management will assume a more uniform pattern, and that this trend will be accelerated by government guidance and regulation as the nation seeks both to enhance and balance its scientific effort.

Indeed, a considerable standardization already exists among big laboratories. Differences between academic, government and industrial research are dwindling as all three types of institution have become active along the whole spectrum of research from basic, through applied, to routine testing, though admittedly each still applies the weight of its effort to different parts of the spectrum. All three types of institution are also in the business of scientific education and extension, both in training their own staffs and in spreading appreciation and knowledge of science among the wider public. The director of the Atomic Energy Commission's Oak Ridge laboratory, Alvin Weinberg, recently advocated converting that institution into a bona fide graduate school in atomic science to help universities train more scientists while at the same time to bring the benefits of a genuine graduate school atmosphere to the Oak Ridge laboratory.[19] He explained that this was not as drastic a step as one might suppose at first, because the laboratory was already deeply involved in scientific education, conducting seminars at and away from Oak Ridge, granting summer research fellowships to graduate students and university professors, cooperating closely with the Massachusetts Institute of Technology in training nuclear engineers and taking part in other related activities. Other government laboratories, such as those of the Department of Agriculture, the National Institute of Health and the Bureau of Standards, have similar programs, as does industry, although to a lesser degree. Scientists from these laboratories often teach specialized graduate courses in nearby universities and frequently take part in academic seminars. Likewise, professors are often in very close touch as consultants with industrial or governmental research.

In fact, as is well known, there has been a marked tendency in recent years to build new research institutions in close proximity to existing ones, especially near large universities. Towns such as Princeton, Berkeley, Ann Arbor, and Cambridge (Massachusetts) have become enormous centers for scientific research. The main advantage in thus concentrating research facilities is to have easy access to other experts and to allow the constant trend toward specialization to proceed apace unhampered by loss of contact with parent sciences and with other specialties. If the present trend continues, the majority of our scientists will find themselves working in such communities, in environments so organized as to enable each specialist to serve as many of the local research institutions as his capacity permits. An industrial scientist, for instance, could direct research for his own firm, act as a consultant for a government laboratory and teach at a nearby university. Should government desire to organize some crash program, he and others could be quickly marshaled for this task.

From the very beginning of the second scientific revolution, when academic and, somewhat later, industrial science were first institutionalized, we have noted a trend toward blurring the lines between basic and applied research and between academic and non-academic institutions. The professional scientist of stature, like his counterparts in the professionally older fields of medicine and law, practices, teaches, consults, writes and keeps learning more about his discipline. While on the one hand he has necessarily had to surrender some freedom of action upon becoming an employee of a large institution, he has still retained a considerable amount of self-direction by making the most of society's extraordinary dependence upon his scarce and highly specialized services.

He has, however, not gone so far as Thorstein Veblen urged him to go in the years immediately following World War I. At that time, Veblen sought to organize a seizure of industry and government by engineers and industrial scientists, whom one of his disciples called technocrats.[20] The Technocracy was to come into being by the simple expedient of a paralyzing strike during which these specialists would withhold their indispensable know-how. Nothing came of the movement, for Veblen failed to arouse that class consciousness among the technocrats which he felt sure already existed in latent form. Class solidarity and common political action have never developed among scientists and engineers, since those with administrative ambitions and abilities have found their striving toward the pinnacles of power unprejudiced by their technical background. By climbing up the bureaucratic ladder, rather than by revolution, they have steadily increased their number and influence in the high places of industry and in such government agencies as the National Aeronautics and Space Administration, the Atomic Energy Commission, the National Institute of Health, the National Science

Foundation, the Bureau of Standards and the many research divisions of the Departments of Agriculture and Defense.

It is in some ways surprising that the technocrats have not thus far achieved an even greater control of our society. Businessmen, lawyers and professional politicians continue to predominate in those key positions where the weightiest decisions affecting our national well-being must be made. That this is so may be attributed to the fact that all these professions require the skill of persuasion, and beyond that a keen insight into the ways of men and organizations. Among scientists and engineers such skill and insight often remain underdeveloped. By personal inclination, training, and early job experience they are more likely to focus on scientific and material problems. Yet as the institutional character of science continues to grow, and conversely as the scientific aspects of the work of more and more institutions increase in significance, researchers will wish to sharpen their managerial and cooperative capabilities. As they develop this aspect of their profession, we can look for a still greater influx of scientists into positions of high influence than has occurred to date.

References

1. In England, for example, 70 to 75 per cent of a total of 550 graduate chemists were employed in teaching at the beginning of the twentieth century. This percentage steadily decreased, especially after 1918, as graduate scientists who entered industry proved their value to entrepreneurs. In Germany, the shift in favor of industrial scientists occurred earlier; by 1900, 4000 chemists alone were working for business and manufacturing firms there. There is a need for detailed statistical studies to be done for the United States. See D. S. L. Cardwell, *The Organisation of Science in England: A Retrospect* (London: 1957), pp. 135, 155, 160.

2. See especially Arthur D. Little, "The Chemist's Place in Industry," *Journal of Industrial and Engineering Chemistry*, II (February, 1910), 63–66, and Alexis F. du Pont, "The Du Pont Company and Francis G. du Pont, With Special Reference to the Years 1887 to 1900 Inclusive," in Allan J. Henry (ed. and comp.), *Francis Gurney du Pont: A Memoir* (Philadelphia: 1951), I, 14–16.

3. Raymond Stevens, "Little, Arthur Dehon," *Dictionary of American Biography*, XXI, 500–501; N. R. Danelian, *A. T. & T.: The Story of Industrial Conquest* (New York: 1939), pp. 98–100.

4. See William A. Hamor, "Duncan, Robert Kennedy," *Dictionary of American Biography*, V, 511–512; Robert Kennedy Duncan, "Temporary Indus-

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5. John J. Beer, "Coal Tar Dye Manufacture and the Origins of the Modern Industrial Research Laboratory," *Isis*, XLIX (1958), 124–125.

6. See "Patents and Profs," *Wall Street Journal*, February 7, 1961, pp. 1, 8.

7. Simon Marcson, "Decision-Making in a University Physics Department," *American Behavioral Scientist* (December, 1962), p. 37.

8. W. Rupert Maclaurin and R. Joyce Harman, *Invention and Innovation in the Radio Industry* (New York: 1949), pp. 172–176.

9. On this and other aspects of the development of the General Electric Laboratory, see Kendall Birr, *Pioneering in Industrial Research: The Story of the General Electric Research Laboratory* (Washington, D.C.: 1957), and Laurence A. Hawkins, *Adventure Into the Unknown: The First Years of the General Electric Research Laboratory* (New York: 1950), *passim*. For a biography of Whitney, see John T. Broderick, *Willis Rodney Whitney: Pioneer of Industrial Research* (Albany: 1945).

10. Simon Marcson, *The Scientist in American Industry: Some Organizational Determinants in Manpower Utilization* (Princeton: 1960), pp. 70–71.

11. Bruce F. Gordon and Ian C. Ross, "Professionals and the Corporation," *Research Management* (November, 1962), pp. 493–505.

12. F. Russell Bichowsky, *Industrial Research* (Brooklyn, N.Y.: 1942), p. 120.

13. Robert K. Merton, *Science and the Social Order* (New York: 1952), p. 234.

14. Earl W. Lindveit, *Scientists in Government* (Washington, D.C.: 1960), pp. 35–54.

15. At the time of Lindveit's publication, about half of industry's research and development expenditures were derived from federal government contracts. *Ibid.*, p. 8.

16. J. Herbert Hollomon, "Science, Technology, and Economic Growth," *Physics Today*, XVI (1963), 42, 44. Unfortunately, Mr. Hollomon does not indicate what proportion, if any, of these scientists and engineers are academically employed.

17. *Ibid.*, p. 38.

18. *Ibid.*, p. 40.

19. Alvin Weinberg, "The Federal Laboratories and Science Education," *Science*, CXXXVI (1962), 27–30.

20. Thorstein Veblen, *The Engineers and the Price System* (New York: 1944), p. 71. This chapter was first printed as "The Captains of Finance and the Engineers" in *Dial*, 66 (June 14, 1919).