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An Industrial View of Research Trends[1]

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CONSIDERATION OF RESEARCH TRENDS from the standpoint of industry calls for an evaluation of the shortage of men and women with scientific training and the relationship of industrial research to research in government agencies and universities; possible or prospective changes in our patent laws also must be weighed. The first and most pressing need is quickly to adjust industrial research to the greatly modified conditions brought about by the dislocations of the war. The second is to adapt it to the changes resulting from the tremendous commercial expansion of this country.

Everyone is aware of the growing inflationary trend whereby all things are becoming more costly in terms of dollar values. Because of governmental controls to combat inflation, increases in selling prices of goods have been held down in relation to the cost of developing or producing the products. This has resulted in research becoming much more expensive in proportion to the profit on the product output.

Inflationary trends, coupled with the shortage of skilled personnel, have raised the salaries of research workers to a figure well beyond any previous level. In our particular field the research laboratories are paying Ph.D.'s, just out of school with no special experience and only average ability, initial salaries which are approximately double those which the superior graduates received in academic or research positions ten to fifteen years ago. Men of somewhat greater experience and ability expect, and are receiving, salaries greater than those of most university professors, at a time when their technical skill and experience are equivalent to those of perhaps only university instructors or assistant professors. Not only have the salaries advanced to new high levels but the costs of chemicals, glassware, and other items of operating expense have gone up, so that the total cost of running laboratories is approximately double what it has been previously. One result of this increased cost of research is that problems have to be evaluated most critically now that they cost so much more to investigate. Another side of the same picture is that if a fixed budget is being maintained, the total amount of research which can be accomplished is limited by the greater expense of each project.

It would appear that industry is in a better position to meet this particular situation than are laboratories of the Government and universities. Industry will be able to adjust the selling price of the products it manufactures to their new cost as soon as there is a return to conditions of free competitive enterprise. Government also is undoubtedly better off than the universities as far as research cost is concerned, although, in response to the demand to reduce taxes, the availability of funds for governmental research will be more limited than under wartime conditions.

As a result of the tremendous growth of American industry there has been a remarkable increase in the amount of industrial research during the past two decades. At the present time industrial organizations are doing probably twice as much research as all other agencies in the country combined, especially if emergency-induced war research is excluded. The figures are not completely available for recent years because of various war-imposed restrictions. However, the general position is rather clearly indicated by Table 1, which was presented in Vannevar Bush's report to the President, entitled *Science, the endless frontier.*

The shift of research towards industry creates problems which must be carefully considered. Industrial research traditionally has consisted primarily of developing and perfecting the application of the fundamental discoveries made in noncommercial laboratories. Development of new fundamental knowledge cannot be maintained at adequately increasing rates if university research does not accelerate with the industry which it feeds. For this the universities

[1] Presented as part of a panel discussion of "Science in the Postwar World" before the Eastern New York Section of the American Chemical Society, 13 October 1945.

need more income. The greatest deterrent to the growth of university research funds is present tax regulations, which hamper donations of money. Modification of existing tax laws and rulings could be readily made so that such donations would be stimulated to the point of restoring the universities' relative position in the country's research. Such a means of accomplishing this objective would be highly desirable, since it would place the control of the spending of such money in the hands of skilled university administrators whose success with such funds has been amply demonstrated.

TABLE 1

SCIENTIFIC RESEARCH EXPENDITURES

Year	Industry	Nonprofit industrial research institutes	Goverment (Federal and State)	Colleges and universities	Research institutes	Total scientific research expenditures
	Millions	*Millions*	*Millions*	*Millions*	*Millions*	*Millions*
1920	$ 29.4	....	....	...	..	....
1921	37.4	....	....	...	..	....
1922	44.0	....	....	...	..	....
1923	50.0	....	$ 15.6	...	..	....
1924	58.0	....	16.3	...	..	....
1925	64.0	....	18.0	...	..	....
1926	70.0	....	16.9	...	..	....
1927	75.9	....	17.1	...	..	....
1928	88.0	....	17.7	...	..	....
1929	106.0	....	22.8	...	..	....
1930	116.0	$ 0.56	24.0	$20.3	$5.2	$166.1
1931	131.3	1.2	26.9	...	5.2	....
1932	120.0	0.99	40.0	24.8	5.1	191.0
1933	110.2	0.74	....	...	4.8	....
1934	124.0	1.5	22.2	19.2	4.7	171.8
1935	136.0	2.4	25.3	...	4.7	....
1936	152.0	2.5	33.8	25.0	4.7	218.1
1937	160.0	3.5	40.7	...	4.6	....
1938	177.1	4.0	49.3	28.4	4.5	263.7
1939	200.0	5.0	....	...	4.5	....
1940	234.0	6.1	69.1	31.4	4.5	345.2
1941	....	9.1	207.2	...	..	....
1942	....	14.0	332.1	39.5	..	....
1943	....	....	561.5	...	..	....
1944	....	....	719.8	...	..	....

From Bush, Vannevar. *Science, the endless frontier: a report to the President.* Washington, D. C.: U. S. Government Printing Office, 1945. P. 80.

If the universities are not enabled to carry on their fundamental researches at a pace commensurate with the need, then industry, as a matter of self-protection, will have to devote increasing attention to this type of research problem. Probably this would be desirable in the long run. Some industrial organizations are now actively promoting such studies; however, their contributions form only a small part of the total fundamental discoveries being made. Before this type of investigation can be pursued by industry to an adequate degree, management will have to be convinced of the necessity of such studies. The directors of research will have to demonstrate to Boards of Directors that money spent in such research is as productive in the long run as is applied research designed for immediate commercial application. Whole new industries can spring up as a result of fundamental research if this is developed under sound leadership. The important thing is to uncover new fundamental facts, for there will be good prospects of finding manifold practical applications of them. Good recent examples of this type of development are found in the plastic industries and in the production of nylon and related products as a result of the study of the fundamental chemistry of high molecular weight polyamide polymers. Another is based on the thermionic tube, which was made possible only by fundamental discoveries on the behavior of gases in a vacuum.

A serious implication of the shift to industrial research is the change this is producing in the availability of trained scientific personnel. Industrial research laboratories depend almost exclusively on university-trained scientists for the direction and prosecution of their research programs. If universities become overshadowed by industrial research activities, it will be increasingly difficult for them to retain qualified investigators who are capable of training the research men of the future. Not only does this involve routine classroom instruction, but also those intangible qualities of inspiration and leadership. One of the most valuable qualifications for a university scientist is an ability through personality, force of character, and enthusiasm for his subject to attract to him and to the subject he represents neophytes eager to join him in enjoying the beauties of his field. These qualities of leadership also make him a desirable man for an industrial research post. If the academic scientist has to leave the university to earn an adequate livelihood for his family, not only is the university bereft but also industry, which is depending upon him to recruit and train its future research workers. The answer to this is obvious: it is to the long-term advantage of industry to see that university professorships remain attractive enough to compete on equal terms for the personnel needed for educational functions.

The problem of trained personnel has been greatly accentuated by the developments occasioned by the war in the last few years. No one could reasonably have anticipated that the National Government, poorly advised by those on whom it relied, would cut off the supply of future scientists by compelling the reckless siphoning of these individuals into the military services. One of the most serious blunders of our wartime policies was the failure to jealously husband our present and prospective scientific workers so that the strength of the nation could be fortified through increased research development, rather than weakened. This viewpoint has been publicly reiterated by many of our most influential scientific leaders without eliciting any persuasive or convincing official explanation of the motives or reasoning alleged to justify such draft policies. A heavy load of responsibility rests on the shoulders of those who condoned, if they did not actively advise, this widespread, indiscriminate drafting of present and potential scientific workers. The extent of the diversion of manpower from research as exemplified by the Ph.D. group has been summarized by Dr. Bush's committee (Table 2). It will be realized immediately that these sixteen thousand research scientists diverted to war were entirely inconsequential from the standpoint of military manpower needs in view of the fourteen million people we had under arms. However, withdrawal of this many from the research group represented a percentage loss to research which will require a decade to overcome.

TABLE 2
DEFICIT IN SCIENTIFIC PERSONNEL

	Accumulated deficit, 1941 through 1944	Estimated deficit, 1945	Total 1941 through 1945	Probable deficits, 1946 through 1955	Total probable deficit due to war, 1941 through 1955
Chemistry	240	550	790	4,460	5,250
Engineering	148	82	230	730	960
Geology	63	50	113	317	430
Mathematics	161	100	261	939	1,200
Physics	251	160	411	1,589	2,000
Psychology	96	84	180	550	730
Biological Sciences	665	725	1,390	4,910	6,300
Totals	1,624	1,751	3,375	13,495	16,870

From Bush, Vannevar. *Science, the endless frontier: a report to the President.* Washington, D. C.: U. S. Government Printing Office, 1945. P. 171.

Industry must adopt special measures to meet the present and future shortage of trained personnel. One method, which will be of moderate help, will consist of additional training and education of present junior staff members. Upgrading the more capable individuals through promotion of extension courses, special training programs in the industrial laboratories themselves, and other means may in some small part supply additional people at higher levels of attainment.

Another means of helping to fill this gap will be to stimulate the education of new research workers in universities by making their training programs more attractive than others available to the returning veteran. This means that universities must have generous fellowship funds whereby men who wish to return for scientific education can be supported adequately. A man who has been out of college and in the military forces for several years, and has possibly accumulated family responsibilities, has matured to such a degree that he cannot be expected to go back for three or four years of schooling unless his economic position during this period is made not too unbearable. Some financial help will be provided through the re-education programs of the Government, but it is not clear at this time whether such provisions alone will prove sufficiently attractive to tip the balance of distribution in any significant manner.

Another means by which industry might help meet the manpower shortage is by creating joint research programs with universities and research institutes. This would, in essence, make these endowed or academic research laboratories extensions of the industrial organizations. Any such widespread program would be dangerous for both industry and universities unless it were carried out with great circumspection. For industry to depend upon university scientists for any considerable part of its research would be to put the universities in the position of having to accept research projects, time schedules, and the other attributes of industrial research which would not properly fit into the academic scene.

If a university scientist is induced to supplement his income by conducting a significant amount of research for industry, then this cannot help but divert his interest, and a disproportionate share of his energy, from his primary academic functions. It is true that university professors can contribute effectively to industrial programs by giving periodic advice along the lines of their special knowledge and training; but when the association goes further than this, it must be at the expense of the universities' needs. Therefore, the industries should restrict their demands on the academic scientists, primarily relying on them to a limited degree as consultants in fields of their special interests. Industry should also support, as far as its resources permit, the fundamental research and educational programs of the man or the institution through grants of fellowship funds. To the largest possible degree these grants should be entirely unrestricted so that they could be used either to promote training in research or to expand fundamental research without regard for its commercial implications. The grants should not be used as levers, even indirectly, to force the prosecution of applied researches of immediate commercial value. For this latter type of work special short-term arrangements should be made.

Some in industry feel that a serious problem presently to be faced arises from the accelerated development of governmental bureaucracy in research. Under the impact of wartime necessity, numerous research projects were set up under governmental auspices to obtain answers to specific questions in the shortest possible time. These projects drew freely and practically without restriction on the trained personnel of the country. Almost without exception they had the best ability of the country at their command; their funds were, for all practical purposes, unlimited. As a result of the intensive work which this made possible, numerous important problems were advanced rapidly to stages which would have been reached only after many years under ordinary peacetime conditions. An unfortunate aftermath is that there is a possibly natural tendency, especially in those participating in these programs on a full-time basis, to feel that they have a vested interest in the continuation of the programs beyond the time of the national emergency which necessitated or justified them.

Consideration of the monetary and manpower-hour expenditures on these governmental wartime research projects as a whole reveals a low scientific return on the investment. This is not because of any failure of the persons involved to contribute their best efforts, but rather results from the inherent nature of the situation. The expenditure of even millions of research dollars at a forced draft rate is not an adequate substitute for original ideas. Without fertilization by the flashes of genius which break open new fields for investigation and point out unexplored concepts, the piling up of manpower hours simply multiplies the accumulation of relatively inconsequential details. Many of the war-inspired research programs demonstrate eloquently that piling up data and expending money in a research program cannot make up for the lack of novel concepts worthy of such extensive study. The great hazard in all the present proposals of governmental stimulation of research through subsidies arises from the fundamental truth that large volumes of research are not often adequate substitutes for high quality and originality.

Another danger in the mass approach to research, particularly in peacetime and where the funds are supplied from governmental sources, is that it might put the educational institutions at the mercy of administrators whose ability in the political manipulations required to get appointments would outweigh their qualifications as scientific executives. In the hands of irresponsible theorists such bureaucratic research projects could become instruments for promoting ill-conceived and unscientific political, economic, or social philosophies. The recent history in Europe provides sufficient tragic examples of the perversion of research by government to demonstrate that these possibilities are not entirely imaginary. The leverage provided by the administration of the huge research funds proposed could dislodge the entire balance between our present educational system and industrial research if not exerted with consummate skill.

The viewpoint seems to be held in certain governmental circles that size and economic prosperity are synonymous with social undesirability. There appears to be a tendency to want to discredit the methods of organizations which have been outstandingly successful, simply because of their success. An example of this is the attack on our patent system. One proposal which is being actively discussed in Washington is to compel licensing of all patents. The idea of the proponents of such a policy is that thereby patents would be made freely available to all, which would result, in some ill-defined way, in an improvement in the general welfare. However, compulsory licensing of patents actually would have just the reverse effect. A patent is a contract between the Government and the discoverer which provides that he can have exclusive use of his invention for a limited period of years in return for making it freely available to everyone thereafter. If availability for use by all, even at a license fee, is to come from the moment of disclosure of the invention, then there usually would be little reason for having a patent. The welfare of the inventor would be much better advanced by keeping his invention secret for commercial exploitation. Thereby he could maintain for a longer time the monopoly which he had created for himself through the stroke of genius which constituted his invention. A further serious consequence of compulsory licensing of patents would be to decrease the amount of patenting and disclosure thereby of new scientific information. At present, patents constitute an important part of the scientific literature. This would be choked off if patenting were discouraged by compulsory licensing regulations.

Some argument is made that compulsory licensing of patents would keep powerful companies from preempting entire fields of commercial development through broad, multiple-patent coverage. This argument gains whatever force it may have by being tied to the assertion that, through such patent control, small industry or the small businessman is being squeezed out of the competitive picture. It is difficult to see how the compulsory licensing of patents would modify the fact that a large, well-run company might be able to manufacture some item and to distribute it more economically than a small organization which lacks the resources and trained personnel of its larger rival. If there were compulsory licensing of patents, the small manufacturer would be worse off than previously, because he would have no way of maintaining an exclusive market for the product of his invention during the period needed for its preliminary commercial development and establishment on a firm business footing. The result of compulsory licensing would simply be the expansion of the large efficient units at the expense of the smaller ones.

If there is misuse of patents by industry to create unjustified monopolies or to extend them beyond the bounds which are prescribed by law or which are socially desirable, then there is adequate redress available in the various enactments bearing on restraint of trade, unfair competition, antitrust acts, etc. These can meet any legitimate need of the circumstance and have, of course, already been widely used for this purpose.

Finally, if industry and industrial research are to continue increasing in strength and productivity and thereby contribute to national welfare, they must have an atmosphere of assurance that they will be permitted to reap a fair reward for the results of their researches. In such an atmosphere of confidence the leaders of industrial research will feel that they stand on firm ground, from which unparalleled progress is inevitable.

Study of Experimentally Deformed Rocks[1]

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THE TIME HAS FINALLY COME when research no longer has to be restricted to purely military objectives. A particularly important subject for postwar geological research is the continuation of the study of experimental rock deformation that just got off to a good start when it was necessarily interrupted by wartime activities. At the request of the chairman of the Division of Geology and Geography of the National Research Council a Committee on Experimental Deformation of Rocks was organized in 1944 in connection with postwar planning in order to formulate a systematic program for the work, a sort of target at which to shoot in postwar research.

A special microscope technique, known as petrofabric analysis, which has been perfected during the last twenty years, has made it possible to visualize the way in which the more important rock-making minerals, in particular quartz, calcite, mica and feldspar, are arranged in rocks. This spatial visualization has proved that in practically all intensely folded and metamorphosed rock terranes some vectors in the rock constituents, either dimensional or crystallographic or both, are lined up in certain definite patterns of preferred orientation. That is to say, all the inequidimensional grains of calcite in a marble or of quartz in a quartzite may lie with their longer axes parallel. Or all of certain crystallographic directions such as the optic axis in quartz or calcite, or all of certain crystal planes such as the basal plane in mica, may be arranged in definite spatial patterns. The inference that this preferred orientation in rock constituents is induced by the type of movement followed by the constituents during rock deformation has opened up a new path of investigation of the mechanics of crustal movement.

But as long as the geologist cannot do as the metallographer does with his ductile metals, that is, deform rocks and determine how the position of rock constituents has been changed by the deforming movement, the kinematic interpretation of petrofabric diagrams must remain, like too many other geologic conclusions, a matter of more or less well-justified inference.

We know that these petrofabric diagrams differ in symmetry and in type, but what do these differences really show and how can we *prove* that they mean what we think they must mean? To establish a sound scientific basis for interpretation we must make the components of at least some rocks assume a definite spatial arrangement in response to some definite deforming force.

Strain to Rupture

Inasmuch as it is not an easy matter to produce a spatially continuous deformation in such ordinarily brittle material as rocks it is natural that the first experimental work on a known rock fabric was to strain the rock to rupture and to relate the ultimate strength to the fabric pattern. This was first done in 1929 by Drescher, who deformed a marble fabric that had been carefully studied in Innsbruck by Felkel, under the direction of Sander. The material chosen for the test was an Alpine calcite tectonite (marble) that showed no outward evidence of anisotropic structure. However, it was collected from what is known to be a zone of highly deformed rocks and it proved to have a marked preferred orientation. It was deformed in direct relation to the tectonic axes determined by the fabric pattern, which had been established by the work of Felkel. The marble was found

[1] Read before the Section of Tectonophysics, American Geophysical Union, Washington, June 1945.