2 March 1979, Volume 203, Number 4383 SCIENCE

Science Futures: The Industrial Connection

Edward E. David, Jr.

There has been a great deal of discussion in recent times about the state of U.S. science and our innovation (1) system. That system has worked reasonably well in the past, but when one looks beyond the surface, it seems almost paradoxical. The lion's share of science is done in the universities and colleges, while technological innovation is lodged in industry. How is it that they get together? Traditionally, there has been a diversity of mechanisms for the transfer of knowledge and ideas to industry and the communication of realistic problems to academic researchers. Some of these mechanisms involve students hired into industry, visiting professorships filled by industrial research people, academic consultants in industry, special courses of study for "retreading" industrial people, professional society publications and scientific meetings, and joint work on government panels.

However, such mechanisms may not be adequate for the future. The fundamental situations of both industry and academia are changing. Industry is being increasingly pressed by competition from abroad as well as at home. New science-based technology is required by industry in increasing amounts, not only to meet this competition, but also to satisfy environmental, safety, and efficacy demands economically. The universities and colleges find themselves in an uncomfortable squeeze by their major research sponsor, the federal government. There is less effective funding on one hand and increasingly onerous regulation on the other. The situation will be aggravated by the falling numbers of students expected in the years just ahead. Academia's greatest need is for long-term support from outside government that will pay the true cost of research. Many administrators and professors view that as highly preferable to arm-wrestling government auditors to stay financially solvent. The time has come for a closer and more intimate relation between industry and academia, but a relation that still recognizes their distinct roles in society.

This article sketches this situation in greater detail, as I discuss the essential features of the U.S. research and development (R & D) system, looking at characteristics of industrial research and of academic research as they might affect any partnership and pointing to the beginnings of this desirable industrial connection.

Essential Features of the U.S. Research and Development System

The R & D system in the United States is complex and almost defies a neat description. Yet it does show essential features. None is more important than pluralism. Pluralism is provided by the many existing independent institutions. Each has its own role in society. Each secures its own funding and performs research aimed at its own and its sponsor's objectives. Pluralism of funding sources is particularly important given the troubling trend in academic-government relations.

Another element of pluralism is decentralization. That is a widespread theme of management today as corporations and institutions grow. Centralized policy decisions based on macro concepts of the issues have been found wanting when applied to the many diverse situations that arise. A great deal of local autonomy is required for successful and efficient operations. Needless to say, this way of operating is particularly applicable to research and development.

At Exxon, decentralization is a way of life. Our development activities are dispersed over the operating units of the corporation. However, research and engineering are largely performed centrally. The yearly budget is an aggregation of individual budgets modified and approved by central management review. Thus, management proceeds from the bottom up, not the top down.

The second distinguishing feature of the R & D system is its adversarial-competitive nature. In many cases, it is against the law for industrial research groups to coordinate their programs. The scene is typified by numerous groups working independently and competitively. For example, there are at least three major coal liquefaction projects in the United States at present. There are several others in the earlier stages. Multiple solutions or products tend to emerge from such competitive efforts, and these then vie for public favor. Corporations that excel in this competitive process become self-sustaining through reinvestment of funds in new or improved products or processes. But competition and adversarial relations are not restricted to industry. Laboratories in universities and colleges as well as some government laboratories compete for professional recognition, prizes, and future funding.

The third feature of the R & D system is its dependence on people. Personal excellence and leadership in R & D are highly valued. The rewards can be great in both satisfaction and more tangible terms. The competitive atmosphere means that the most effective people tend to rise to positions of responsibility

The author is president of the Exxon Research and Engineering Company, Florham Park, N.J. This article is the text of the presidential lecture at the AAAS annual meeting on 6 January 1979 in Houston, Texas.

0036-8075/79/0302-0837$01.00/0

and scientific leadership. Maintaining a cohort of achievers is a necessity for a healthy system. This is a major objective for academia, and both government and industry have traditionally aided academic institutions for this purpose.

Despite the importance of these three factors to the health of research, there are tendencies on the national level to deemphasize pluralism, competitiveness based on technical excellence, and dependence on high achievers. This trend is politically driven. Coupled with industry's need for new technology based on science, it implies a driving force for a new synergistic relationship between the scientific community and industry—the industrial connection. Before discussing this matter, let me go further into the state of industrial innovation and the nature of industrial research today.

Industrial Innovation Today

The most recent projections (*2*) of 1979 expenditures by industry on R & D approach $25 billion, continuing a rise in activity over the past 5 to 10 years, except for recession times. This amount is now about equal to federal expenditures. The majority of the nation's scientists and engineers are employed by industry, most of those in pursuits which are aimed at the civil sector.

Beyond such figures, however, there are major transitions in progress. Foreign competition has burgeoned both in domestic markets and where U.S. industry operates abroad. Federal regulations have made it much more difficult and expensive for industry to operate. Foreign governments have thrown up a plethora of protective screens which restrict access to their markets. Economic nationalism is on the increase.

For industry, the bottom line from these pressures is the growth of uncertainty and the corresponding increase in risk for investment in new businesses and facilities. The industrial management culture can handle almost any well-defined situation. It is bewildered by uncertainty, particularly that generated outside of the market mechanism. Socially generated political pressures are particularly fearsome. Yet, despite these difficulties, I find no industry throwing in the towel. Most are making major efforts to surmount the difficulties and to continue to prosper. It is true that these pressures have focused management's attention on the short term, resulting in a similar concentration for research.

Beyond this well-documented effect, the market for research is down. By that I mean that there is a decreasing demand for certain of the results of research. This decreased demand occurs in cases where regulation, license requirements, and controls have increased the cost and time for commercialization of products and services that could arise from new knowledge. For example, chemistry is such a field. Marketing a new pharmaceutical or fuel additive is much more costly and time consuming than it was only a few years ago. Regulatory uncertainties also contribute to a decreased demand for research in fields such as medical technology. Some other fields have been less affected; for example, new computer-based products for the calculator, amusement, and business markets. These are still able to make rapid use of new possibilities from research. Overall, however, uncertainty and regulation have been blamed for a major decrease in the demand for innovation. The case cannot be proved except in some specific instances, but in my opinion it is real and substantial. There is no reason to believe that this regulatory situation will recede, despite its negative influence on economic growth, and despite the spoken intentions of top government officials to invigorate innovation.

Actually, the situation with industrial R & D is healthier than is indicated by this outlook and much of the current rhetoric. There is a remarkable degree of vigor in evidence at industrial laboratories. Indeed, because of or in spite of increasing regulation and competition, many industries are becoming more technologically sophisticated and require increased science-based research. Many people believe, and I am one of them, that much of the best research today is going on in industry.

I have already noted the troubles that appear in the commercialization phase of innovation. The high cost of money, long lead times enforced by delays in obtaining permits, and uncertainties about liability and the market make commercialization more difficult than ever. However, these barriers have not affected the quality and number of ideas for research. Those with the greatest push will progress through the innovation chain and change the world as in the past. This innovation will be facilitated by high quality research in modeling, public policy, environment, markets, and societal effects. It is this vigorous outlook that gives hope regardless of the obvious impediments to traditional paths of innovation. Industrial innovation will not atrophy.

Nature of Industrial Research

Much of today's discussion about industrial research and innovation has centered around the topics of barriers and incentives to innovation. I have already said that the barriers are not likely to recede, and I doubt that new incentives will offset them. Yet, with suitable adjustments, technological innovation can proceed. A reduction of uncertainty could help, as could fewer, clearer regulations, rules, and standards. There are other matters peculiar to industrial research worth mentioning as they relate to "the industrial connection." A discussion of them will lead us to a number of ways for academic and industrial activities to augment each other.

Let us begin with basic research. There have been endless arguments over the years about definitions of basic research, and I will not repeat them here. However, it is true that industry tends to view basic research very differently than do government or academia. The National Science Foundation (NSF) definition relies upon motivation for the work as the distinguishing feature. According to that definition, the motivation for basic research must be the extension of knowledge and not application. This definition is not appropriate for industry. First, the motivation of the industry and that of the researcher may be different, and often is. More importantly, the NSF definition ignores the character of the work itself and its results. Industry would say that *any* work which produces new understanding is basic research, regardless of the motivation. I could go on with this argument, but I think the point is clear: industry's view of basic research is output-oriented just as is its view of R & D generally.

Let me give two examples. As an industrial researcher, I have no hesitation in saying that the emergence of Information Theory from the Bell Telephone Laboratories was the result of basic research, even though Claude Shannon clearly had in mind its application to the improved design and performance of electronic communication systems. According to the industrial definition, my company, Exxon, has basic research not only in our Corporate Research Laboratory in Linden, New Jersey, but also at our synthetic fuels lab in Baytown, Texas, and in our catalyst activities in Baton Rouge, Louisiana. According to the NSF definition, only a fraction of our Corporate Laboratory work would qualify.

Now this point is not merely a definitional matter. It is the essence of the philosophy behind industrial research. Research in industry is concentrated in fields of obvious importance to the corporation's function in society, and its ultimate aim is to better the performance of that function. Such research should qualify as basic if it is done in the best scientific tradition with the results subjected to peer review, and if it contributes to the knowledge base. More and more corporations are taking this view of research.

That in turn means that basic industrial research is probably larger than current figures would indicate but, more importantly, it is expanding. But the philosophy behind it is a far cry from that of the 1950's and early 1960's. That was the era when many corporations established research laboratories only loosely linked to their function in society. This was an act of faith that unstructured research would produce great results and a sterling image. Disillusionment set in in the late 1960's and many of those laboratories have disappeared. The current emergence of research activities is more measured, but is also much sounder in my view.

Modern industrial research tends to be organized along interdisciplinary lines. Industry is not likely to have chemistry, physics, social sciences, or electrical engineering departments specifically. Neither, however, is there a pure project orientation. Work tends to be organized around macro disciplines or functional lines. At IBM, for example, some of its research is organized around the functional units of computers: logic, memory, organization of data, and software. At Exxon, our research is organized around such subjects as surface science, separation of chemical or physical species, laser chemistry, catalysis, and materials. Our organizational units tend to be strongly interdisciplinary therefore. The subjects are chosen for their importance but also because they are fields where new ideas promise progress.

More than this, industrial research is expanding its scope profoundly. Companies and corporations at one time viewed their interests narrowly—restricting their concerns in research to that clearly involved in the technology of their product lines. Today, a broader point of view dominates the scene. For example, many corporations are interested in policy research, economic models, and the sociology of the cohort from which they draw their customers. Furthermore, they are sponsoring research in these subjects. At least limited interest in the social sciences is also being evidenced. One source of this interest is the very large sums spent by industry on education and training, said to be larger than the total of academic budgets.

Studies of educational methods and techniques are being carried out in many corporate laboratories. Both continuing and remedial education are included, as are both knowledge and skills. There are a number of behavioral laboratories in industry, and a good deal of research on subjects in experimental psychology; for example, in visual and auditory perception and in motor skills. All of this means that industrial research is becoming much more diverse, and is not focused entirely or even principally on hardware or products. Furthermore, the systems approach to design and business planning for innovation is coming to dominate the scene.

I have not even mentioned the environmental, safety, and efficacy fields which themselves are generating major research efforts in industry, as is the effort to make products more reliable, more repairable, and "fail safe" or "fail soft." The research on failure modes of systems is becoming a discipline in itself.

Another aspect of the industrial scene is the increasing cost of development. A case in point is the developmental pilot plant and accompanying experiments for coal liquefaction at Exxon's Baytown, Texas, installation. That program will cost one-quarter of a billion dollars. The era of "big science" is being joined by the era of "big technology." This trend is placing a premium on techniques for containing developmental costs. Thus, research is being carried out on the development process itself.

Another characteristic of industrial research is its insecurity. I do not mean that it fears capricious elimination or even erosion during economic downturns. (Research directors have learned how to manage such swings within limits.) Rather the insecurity focuses on the quality of the research. Industrial managers feel comfortable with development. There the performance goals can be clearly stated, the project can be priced, schedules laid out, milestones established, and so on. The quality of the effort can be assessed against those yardsticks. Managers feel much less comfortable judging the scientific quality of research results. Yet, industrial scientific research requires a high level of stewardship because of its isolation. Individual laboratories are isolated by the competitive nature of industry enforced by the antitrust laws. Cooperative research and exchange of results between industrial research labs is forbidden by law in many cases. Competition also delays publication in some instances. Thus, industrial research can stray far off track before that becomes apparent. Since research in industry, as elsewhere, has a long lead time to commercialization, the usual evaluation tools based upon commercial output do not apply. Thus, evaluation is one of the principal puzzles of industrial research.

This sampling of activities and trends hopefully gives the flavor of industrial research today. It increasingly makes use of the basic research paradigm in forwarding the industrial function. The scope of industrial research is growing apace; not only are policy, social sciences, and behavioral sciences becoming legitimate subject matter, but also interdisciplinary groups are the preferred mode of organization much more broadly today. Systems-thinking is becoming a dominant feature. The cost pressures of "big technology" are leading to research on the R & D process itself. Finally, industrial research has substantial difficulty in evaluating its ongoing activities. This developing picture reveals one side of the industrial connection. Perhaps you will agree with me from this sketch of industrial research that an academic element would be beneficial to industry and would not necessarily be incompatible with first-rate academic research.

The Academic Side

Now turning to academia, there is no doubt that there are increasing administrative burdens on research performers. Professor Wiesner's recent speech (*3*) on the subject has been widely publicized. Dr. Charles Overberger of the University of Michigan has also spoken to this subject when receiving the ACS's Parsons Award (*4*). Both of these distinguished academicians pointed to federal regulations as being a major factor toward increasing the administrative and accounting load on research institutions, as well as constraints and pressures to point their work toward the latest national need or congressional interest. Both Wiesner and Overberger believe that the 30-year relation between the government and the universities is breaking down, or at least changing radically. This trend has yet to run its course.

This is not the only trend affecting research and science today. There is the increasing average age of the tenured faculty in research universities, and the changing employment patterns of young doctoral graduates. One can suggest other trends which promise to affect academic research. The effects are not evident from gross funding statistics. Nor can they be offset by increases in gross funding of research, no matter how much we like to hear of yearly growth in the federal research budget. The effects go to the root of research priorities and style. Traditionally, priorities have been set by the notion of a shortening time scale in response to increased demand for bringing results from the laboratory to impact on society. Style has been set by the idea that research excellence earns increasing autonomy in day-to-day work. Federal policies imply that these ideas no longer reflect the situation.

Just how the universities, and research and science generally, will adapt to these changes is not clear. It is clear that the prominent features of the R & D system listed earlier are worth preserving to keep the system effective. I believe that the industrial connection can aid in preserving these features.

Strands for the Industrial Connection

Academia and industry have had a long and fruitful relationship. The colleges and universities have been the suppliers of scientists and engineers. Industry has been more or less generous in its support of academia. However, when the federal government increased its support to record levels in the 1950's and 1960's, industry did not try to compete. Many of its fellowship and scholarship programs were dropped in favor of NSF, NASA, and NIH. Industry had never supported substantial amounts of research in academic institutions. However, there were some continued contributions for specific purposes. Industrial associates programs emerged at the universities in the 1960's and provided some small income for the universities and a link to industry. But most of this sort of activity might be described as philanthropic and does not result in a working connection. I hasten to add, however, that contributions of relatively modest unrestricted funds to the universities can produce benefits far out of proportion to their amounts.

Well beyond this mode of philanthropic interaction is joint research. Of course, there has been much lip service to such joint projects in the past. But major efforts have foundered because of the conflicting roles seen by the potential participants. Issues hinging on patent ownership and licensing, publication rights, protection of proprietary data, and so on have proved difficult to resolve. However, in recent times there has been progress, perhaps due to the pressures on industry for innovation and on academia for long-term, unconstrained support.

Harvard University and Monsanto have negotiated an agreement in which the knotty issues have been largely resolved. The agreement provides support for certain selected faculty members and some of their students on a long-term basis, say 5 to 10 years. There are provisions for Monsanto scientists to become involved and to work jointly on ideas and research topics. Rights to inventions are arranged so that Harvard retains ownership of its own contributions, but provides exclusive license to Monsanto for a specific period providing the inventions are progressing toward commercialization. The agreement itself is a complex document but it is remarkably cooperative in tone. Other companies including Exxon are exploring such long-term cooperative arrangements.

Academic advisors for industry have a long history too. Most often the arrangement is through a consulting contract. However, a broader instrument, the outside advisory committee, composed of distinguished scientists, is becoming widely used. For example, IBM, General Motors, and Gould, among several others, have such committees. Some advisory committee members are also on the corporate board of directors. Such committees evaluate programs, particularly helping with that vexing evaluation of research to which I referred earlier. They also provide a direct route for voicing research ideas and imperatives to the top management.

Another area of increasing importance for academia-industry interaction is the study of public policy issues. Such studies are increasingly dependent on sophisticated models, economic and otherwise. Studies done by the industry affected by the policy are not credible. Thus, the university can play the role of the honest broker. To avoid even the appearance of conflict of interest, policy studies should have at least several sponsors. Industry support of broad-based activities at university policy centers is perhaps best of all.

I could go on but it seems to me that just the above indicates the rich field for cultivation by the universities and industry together. There are mutual benefits to be gained. The pressures pulling the potential partners together, I believe, are inexorable and fundamental to the evolving situation. I do not expect to see an immediate embrace, but 10 years from now I do expect to see a vigorous community of industrial-academic scientists with its academic members enriching industrial research and industrial organizations providing the link to commercialization.

References and Notes

1. "Innovation" as used here refers to the complete process of bringing new knowledge and ideas to the market place in the form of new products and services, or to the production process or service facility to achieve economies.
2. W. H. Fisher, *Battelle R & D Forecast for 1979*.
3. J. B. Wiesner, *Chem. Eng. News* (11 December 1978), p. 31.
4. C. G. Overberger, *ibid.* (4 December 1978), p. 28.