*Entomol. Soc. Amer.* **48**, 272 (1956); P. T. Haskell and P. Belton, *Nature* **117**, 139 (1956); K. D. Roeder and A. E. Treat, *J. Exp. Zool.* **134**, 127 (1957).
4. K. D. Roeder and A. E. Treat, *Proc. Intern. Congr. Entomol., 11th* (1960), vol. 3, p. 1; ———, *Amer. Scientist* **49**, 135 (1961).
5. K. D. Roeder, *Animal Behaviour* **10**, 300 (1962).
6. ———, *Science* **153**, 1634 (1966).
7. ———, *J. Insect Physiol.* **12**, 843 (1966).
8. ———, *ibid.* **10**, 529 (1964).
9. ——— and A. E. Treat, *Sensory Communication*, W. Rosenblith, Ed. (M.I.T. Press, Cambridge, Mass., 1961), p. 545.
10. K. D. Roeder, *J. Insect Physiol.* **12**, 1227 (1966).
11. R. S. Payne, K. D. Roeder, J. Wallman, *J. Exp. Biol.* **44**, 17 (1966).
12. This work was supported by a research career award and by research grant AI-00947 from the National Institutes of Health. Some of the equipment used was purchased under a grant from the Air Force Office of Scientific Research.

# Basic Research in the University and Industrial Laboratory

University and industrial research directors have contrasting roles in the basic-research enterprise.

R. E. Marshak

Warren Weaver, in an essay (*1*) entitled "A great age for science," tells us that pure science is "not technology, it is not gadgetry, it is not some mysterious cult, it is not a great mechanical monster. Science is an adventure of the human spirit; it is an essentially artistic enterprise, stimulated largely by curiosity, served largely by disciplined imagination, and based largely on faith in the reasonableness, order, and beauty of the universe of which man is a part." This characterization is a bit flowery, but it correctly emphasizes the point that a pure scientist derives his chief satisfaction from fashioning a new piece of knowledge, just as an artist derives his greatest pleasure from composing a symphony or carving a piece of sculpture. The emphasis here is on new knowledge, not merely the accumulation of isolated pieces of factual information, but knowledge of the kind which leads to a deeper understanding of natural phenomena and, indeed, is a contribution to natural law. The basic research enterprise starts with wonder and an intense curiosity about the nature of the world, is fed by devoted and almost passionate activity in search of new knowledge by truly creative individuals, and yields ordering principles where none existed before and powers of prediction which could only be dimly envisioned when the work was started. The objectives of the basic research enterprise are furthered by allowing the individual scientist complete freedom both to choose the subject matter of his investigations and to draw the conclusions to which they lead, consistent with the laws of logic and nature.

The situation is different in applied science. The applied scientist has a practical (that is, human) goal in mind and attempts to enlarge existing scientific knowledge in rather well-defined ways to achieve this specified human purpose; usually the purpose encompasses the creation of new materials, devices, systems, methods, or processes. In other words, applied science comprises the technological applications of newly discovered scientific knowledge. It is a truism that applied scientists may create new knowledge—interpreted in the broadest sense—and that pure scientists, motivated solely by curiosity, may make revolutionary discoveries of the greatest possible practical application. But the point is that applying science to satisfy certain specific needs of man automatically involves the social group which has spelled out this particular set of needs, and we must expect this social group or agency or organization (whether governmental or private) to call the tune. That is to say, a practical goal necessarily imposes constraints and controls on the applied scientist which would hamper productive and original work in pure science.

## Basic Research at a University

After these preliminary and somewhat general remarks, let me try to come to grips with some of the questions which have been put to me. The first major question has to do with how we carry on basic research at a university and what role, if any, the research director plays in planning research programs, selecting scientific personnel, and achieving optimum research performance. Before commenting on the various facets of the research director's job in the university setup, I should like to point out that the preponderant position of the university in the basic research output of the U.S. is not a universal phenomenon. In this country, pure science is pursued largely in university laboratories where the senior scientists pass on the torch to the young students and where the students, through their enthusiasm and inventiveness, help to break down traditional patterns of thought. By combining graduate teaching and research at a single institution, as we do in an American university, we expose our young people to exciting new ideas and the most modern research techniques. Indeed, many research programs at the university are planned so that graduate students will receive the maximum benefit from the availability of up-to-date equipment and contribute significantly to the research. In contrast, in the Soviet Union, for example, the bulk of the scientific research is concentrated in the specialized institutes of the Soviet Academy of Sciences, not in the universities, which play primarily a pedagogical role. In the academy institutes of the U.S.S.R. there is a reluctance to accept young students because, supposedly, they will interfere with the research activity of the senior scientist. The result of the dichotomy between the instruction-oriented university and the research-oriented academy institute

The author is Distinguished University Professor of Physics, University of Rochester, Rochester, New York. This article is adapted from an address presented to the research directors of the Eastman Kodak Company and associated companies at their 1966 meeting held at Shawnee-on-the-Delaware, Pennsylvania.

in the Soviet Union is that the university students receive inferior research training and the academy scientists miss the stimulation of bright young students. This is only one of many reasons for the superior performance of American science relative to Russian, but it is relevant for this discussion.

Another factor responsible for the flourishing state of basic science in the American university is the strong tradition of intellectual freedom in American universities, which, in turn, is sustained by the openness, freedom, and emphasis on individual initiative that characterize the American way of life. To an extraordinary degree the academic scientist is allowed to follow the bent of his own curiosity and the creative impulses of his own mind, and thus the university provides a very favorable climate for the practice of pure science. Further, an essential prerequisite for the prospering of basic research is openness of communication. The scientist doing fundamental research should be free to publish all his results, to receive publications from colleagues in laboratories throughout the world, and to have personal contact with all the experts in his field. Many jokes have been made about the presence of so many American professors at international conferences, but the fact remains that no amount of familiarity with the scientific literature can replace the intellectual excitement generated by the personal exchange of ideas.

Having touched upon some of the qualities of the basic research milieu in the American university which have been so conducive to fresh and daring work and to a research output reflecting a high degree of alertness and sophistication, I shall now focus on the research director's role. Granted the very favorable intellectual climate in the American university for basic research, the research director still faces the problem of selecting the major fields of research, appointing the scientific staff, and focusing on concrete ways to translate the generally favorable atmosphere into programs of high-quality and productive research.

## Selection of Research Fields

With regard to the selection of research fields within the university framework, several considerations enter the picture. In principle, there is absolute freedom of choice, and the energetic research director will attempt to initiate research programs in those areas which have the greatest potential for major advances. If one chooses a field of research which is clearly at the frontier of one's discipline, it will be relatively easy to generate and maintain esprit de corps, the will to achieve, and pride in outstanding accomplishment. Thus, in physics, it is evident that research aimed at investigating the substructure of the elementary particles is one of the great frontiers and that a university physics department with a highly competent and lively high-energy physics program will set the tone and stimulate other research programs within the department to higher levels of achievement.

Similarly, in the biological sciences, an active program in molecular biology, with its tremendous accomplishments to date and the prospect of breaking the secret of life, will inspire research workers in other areas of biology, showing them that basic research is a quest for new knowledge and fundamental understanding and not just another job to be done. A third frontier of research illustrates the practical limitations which a university research director must recognize. I refer to the recent developments in astronomy relating to quasars and other objects far out in space, which may shed light on the origin of the universe and its future evolution. This is certainly a frontier field, and any research director in astronomy would be delighted to set up a research program in this area.

## External Constraints

These illustrations immediately suggest the external constraints which any sensible university research director would respect—namely, availability of funds, availability of personnel, and accessibility to the large scientific installations which may be essential for the chosen research. There is no point in attempting to start research programs in the truly frontier areas of science unless one is confident of recruiting persons of high competence, since it is precisely in these frontier fields that meaningful research can be carried out only by highly intelligent and dedicated scientists. Funds will, of course, be easier to come by if scientists of high quality have been recruited, but the funds are not unlimited, and in some cases the demands in terms of equipment and supporting services are so great that the anticipated budget is totally inadequate for serious research in a rapidly advancing field. The research director at the university must also take cognizance of the fact that large scientific installations are finite in number and not equally accessible to all university research groups. Not every high-energy physics group can expect to have a large accelerator on its university campus, and the astronomers in the eastern part of the United States must accept the fact that the climate of the western part provides better viewing conditions and hence ensures better sites for the construction of large optical telescopes. It is possible, of course, to set up so-called university users' groups in high-energy physics, in cosmological astronomy, in space physics, and in other branches of science requiring large installations; this is being done in many places, but it creates its own problems (for example, with regard to teaching) and must be handled with care.

## Critical Size

I should like to make several other points concerning the selection of fields by a university research director. First, superior research productivity in a small number of fields should always be given preference over widespread coverage and undistinguished performance in a great variety of fields. I am firmly of the opinion that, in order to be truly effective, each research program must be of a certain critical size, which depends on the nature of the program. If the group is smaller than the critical size, the rapid pace of scientific development within the field may swamp the intellectual absorptive capacity of its members and lead to a lack of self-confidence and to fragmentary and uncritical research output, outside the scientific mainstream. If the research group is of critical size, there will be a strong interaction among its members, the talents of the individual members will complement each other, and the research work will gain in scope, depth, and value. I am not implying that each research project should become a group effort; the resulting loss of spontaneity and creativity on the part of the individual investigator would be too steep a price to pay. But I do think that the close proximity of a suitable number of persons working

in the same general field tends to enhance the research productivity of each member of the group, provides natural teammates for particularly intractable problems, and in general keeps everyone professionally alert. Part of the critical-size problem is the securing of a judicious mix of theoretical and experimental staff so that experimental research proceeds on a level commensurate with the theoretical understanding of the subject. Finally, a university research director must keep in mind the possibilities of cooperation and interaction between the scientists in his own laboratory and those in other laboratories at the university and in laboratories (if any) in the neighboring community.

### Selecting Staff Members

After some broad decisions have been made with regard to the choice of fields, the research director at the university must face the problem of selecting appropriate staff. It is sometimes said that in universities one simply selects gifted scientists and pays very little attention to the fields in which they work. This is not quite true. If I wish to build up a research program in high-energy physics, a Nobel laureate in solid-state physics will not be too helpful, although I would always be pleased to appoint one to the staff (provided the university authorities did not eliminate the high-energy physics professorship when this appointment was made). However, it is generally true that, within the field of high-energy physics, for example, I would not try to define too sharply the specific research program for which I was recruiting but would pay more attention to the native ability and scientific potential of the individual. It is very important to remember that one outstanding researcher is worth a large number of lesser ones, and that inevitably, as the field develops, both the research problems and the experimental techniques may change radically. The research director cannot hope to keep up with all the latest developments, and he will have to rely on the wisdom and good sense of the scientist placed in charge of a given program.

Several other aspects of the personnel selection process are worth noting. In my opinion it is extremely important, in selecting personnel, to match the seniority of the scientist to the complexity of the research program and the level of responsibility over it which is being assigned him. A fresh Ph.D., or even one with several years' experience, may be too great a risk for a particular program of some magnitude and importance. Moreover, a university research director should attempt to do as much of the recruiting as possible himself, at the more junior as well as the senior levels. This places him in a better position to make the hard decisions later on with regard to promotion or termination of appointment. It is well known that the probationary period for junior appointees at American universities is rather rough, theoretically being as long as 8 years, although in practice it is more like 5. By involving himself personally in the selection of staff at the immediate postdoctoral level, the research director at the university can keep his eye on the progress of the individual scientist and can increase the probability that the final decision with regard to tenure is a just one. In the long run, the members of the department with tenure provide the continuity and stability for the research programs and set the overall style of operation.

### Intellectual Environment

I have spoken of the intellectual environment which must exist if basic research is to flourish at a university—or anywhere else, for that matter. The research director must guarantee to every scientist on the staff absolute freedom to select his problems, to choose research methods, and to appraise and explore new research opportunities as they arise. He must realize that the creative scientist is, almost by definition, a nonconformist. (Let me quickly add that the nonconformity of the creative scientist lies in the realm of ideas and not necessarily in that of behavior!) The research director will also recognize that the more creative scientist will be less concerned than the less creative one with the quick achievement of results. The more creative scientist prefers to work more slowly at first, developing his methods of attack, then moving quickly, with assurance, to the solution of the problem. The research director must be patient with some of his best people; when the research is completed, he can expect a deeper and more lasting contribution from the more gifted members of his staff.

As I have already remarked, openness of communication is the lifeblood of pure science. Free and rapid publication of research results, frequent attendance at meetings, and other types of personal association with professional colleagues—all are part of the continuing process of education, of intellectual stimulus, and of preparation for future research problems. Indeed, the communication of knowledge is an important mechanism of scientific progress, and it is the function of the research director at the university to eliminate all impediments to such communication.

There was a time when a research director at a university would be thought to be doing an admirable job if he ensured a good "creative environment" for the scientific work in his laboratory. But now the conditions of intellectual freedom are regarded as inalienable rights and are strongly sustained by the tradition of academic freedom, which is accepted without reservation by the leading American universities. The research director in an American university must therefore provide positive inducements to the research scientist: a sufficient number of assistants; adequate space; assurance of funds for obtaining complex research tools and supporting services; sabbatical leaves; and tangible incentives in the form of recognition and emoluments. When he has supplied these positive inducements, together with the proper intellectual environment, the research director at the university has come to the end of his road. If he has made a wise choice of research fields and has appointed talented and creative individuals to the important positions, there is not much more that he can do. All the essential ingredients have been put into the pot, and he must await the outcome with a silent prayer. To judge from the experience of recent years, it is likely that his prayer will be answered—with luck, answered with some major contributions to knowledge.

### Basic Research in an Industrial Laboratory

If these are, in fact, the proper guidelines for a university research director, let us now consider the degree to which these guiding principles are germane to the role of the research director in an industrial laboratory. It is clear at once that the industrial research director does not possess the same freedom in choosing research programs. In con-

trast to the university research director, who labors under no intrinsic restrictions on the choice of programs, the industrial director must consider the relevance of the research programs to the type of business in which his company is engaged. Even if the nature of the business is interpreted in the broadest possible terms, as it should be, this imposes a powerful constraint on the industrial director. But, apart from the criterion of relevance, it seems to me that most of the earlier comments apply equally well to the industrial director as regards the selection of fields of research. I believe it is still better to pursue a small number of research programs in depth and to achieve a position of leadership in these fields than to attempt a wide but superficial coverage of a large number of fields. It may be useful to employ a number of individual specialists working in distinct fields, in order to maintain awareness of important developments in areas related to the main programs. But one should not mislead oneself into thinking that it will be possible to make serious scientific contributions in these areas. Further, I believe that the "critical-size" argument is valid for an industrial laboratory, and that adherence to this principle will increase the chances that the quality of research performance will enhance the stature of the company. I also think that the "town-gown" argument can be reversed —and that the industrial laboratory director, in selecting research programs, might take into consideration the possibilities of interaction with university research programs in related areas, if there is a university in the vicinity. Finally, I would emphasize the importance of maintaining a proper mix of theoretical and experimental investigations, if significant contributions to knowledge are to be hoped for.

In selecting personnel for the basic research programs, the director of an industrial research laboratory should, in my opinion, follow most of the guiding principles set forth above for the university director. It is as true in an industrial laboratory pursuing basic research as in a university laboratory that one very talented and creative individual can inspire a substantial number of competent but less imaginative research workers to a high level of performance. In particular, it seems to me that the industrial research director, in recruiting personnel for the basic research programs of his laboratory, need not pay too much attention to the considerations of training and experience and advancement within the company which quite properly play a role in the selection of personnel for the engineering and development programs. By their very nature, the basic research programs are part of the mainstream of science, and it should be possible to judge the capability and suitability of a prospective scientist employee rather independently of his prior association with the company. Moreover, in view of the difficulty of basic research and the slowness with which it gets under way, the probationary period for a junior scientist ought to be as rough in an industrial laboratory as it is in a university laboratory. If an industrial laboratory is expected to nurture, support, and encourage basic research programs, it should also have the right—indeed, the obligation—to terminate, or at least transfer, those persons who do not fulfill their initial promise.

## Concluding Remarks

I would imagine that the foregoing comments concerning the role of an industrial research director in selecting research programs and personnel will not raise any violent objections. I may be entering a more controversial domain when I conclude with some remarks on the ways in which an industrial research director could create a more favorable intellectual and organizational climate for the basic research programs. The industrial director should, I think, make it clear, through official statement and day-to-day behavior, that his company is committed to the basic research programs on a long-range basis; that the methods of evaluating the basic research programs will differ from the methods of evaluating the engineering and development programs; that, by and large, it is not expected that patents will emerge directly from these programs; and, above all, that company management has a positive interest in the programs and proposes to back them to the hilt.

Once the company's attitudes and expectations are thus spelled out, the research director will turn his attention to providing the best possible "creative environment" for the basic research scientists. I refer to such matters as not confusing organizational ability with scientific stature; continuing to regard the scientist as an individual, not as part of "manpower"; shielding the basic researcher from concern about the company's "profitability" (a matter about which the research director himself should be deeply concerned); not allowing the patent department to delay unnecessarily the publication of scientific papers; encouraging attendance at meetings and sabbatical leaves at universities wherever possible; supporting visits by outside lecturers and post-doctoral fellows; and ensuring complete exchange of information among all the company's basic research scientists. Positive measures of this type, taken by the industrial research director, will become known to the scientific community and will be of considerable help in recruiting top-level personnel.

### Reference and Note

1. W. Weaver, in *Goals for Americans* (Alfred P. Sloan Foundation, New York, 1961).
2. I am indebted to Dr. Louis Eilers, president of the Eastman Kodak Company, for the invitation to give the talk from which this article is adapted, and to Allen Wallis, president of the University of Rochester, for suggesting that it might be of interest to a wider audience.