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26a. Recent (unpublished) behavior and electrophysiological experiments which were performed in my laboratory have proved that the bombykol receptor cell reacts to the lowest possible stimulus for a chemoreceptor, namely one single molecule. In the behavior experiments (Dr. K. E. Kaissling), 22 percent *Bombyx* males reacted when less than 10^3 bombykol molecules were adsorbed per antenna. Using adequate mathematical treatment (Poisson-distribution) one can calculate that one molecule-hit suffices to elicit a single-cell response. Electrophysiological recordings (Dr. E. Priesner) from bombykol receptor cells gave corresponding results: Single nerve impulses which are fired by the receptor cell can be correlated to single molecule hits.
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Support of Scientific Research and Education in Our Universities

F. A. Long

No doubt at any moment in time there are people who feel that that particular moment is critical. I say this in apology because I do feel that now is a critical time for the support of science. It seems to me that we are approaching a major decision point on how we will support science in the United States, and specifically on how we will support scientific research and education in universities. If the nation is to reach this decision wisely, it surely needs the most thoughtful inputs possible from the people most involved—the scientific teachers and research scholars. It seems to me therefore of great importance that university scientists think through the problem as clearly as we can, and that, when we have some sense of vision and need, we present our conclusions with vigor and persuasiveness. What I wish to do is outline some aspects of the problem, give some tentative suggestions of things for us to do, and, in general, attempt to initiate what I think is a most necessary and important discussion.

I thought of saying, but hesitated to say, that we had reached the end of an era. On the other hand, I have no such hesitancy in saying that some 20 years ago the United States, and especially its federal government, did embark on what has been a new era in the support of universities and in the relationships between universities and the federal government. I speak, of course, of the decision to support basic research and graduate training in universities by utilizing funds from agencies of the federal government.

It is not characteristic of the United States to make its major decisions in one swoop. Rather, we are inclined to embark on a new line of effort or a new policy by making numerous smaller decisions, all of which then add up to a grand and important total. I think this is a good description of what has happened in the relationships between the universities and the federal government. In a relatively brief period between, roughly, 1946 and the early 1950's we made a set of decisions of major importance—or, more correctly, we put in motion a set of actions which have become translated into major decisions. Let me try to put down what I think were the key things that were done during these important years.

1) We reached a national decision that there should be federal support of higher education, especially at the level of graduate training and research.

2) We decided that the universities would have a central role for the nation in the conduct of basic research in science and engineering.

3) We decided that support for higher education and basic research at universities would be accomplished through a multiplicity of federal agencies, including mission-oriented agencies, such as the Department of Defense and the National Institutes of Health, and agencies more directly charged with support of education and basic research, such as the National Science Foundation and the Office of Education.

These decisions did not come into being fullblown, but the results have been as important to the country as if

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they had. Certainly federal support of higher education is with us in a major way, and no one believes for a moment that the situation will markedly change. More precisely, no one sees the future in any other way than as involving increasing federal support for higher education. Similarly, most of us believe that the universities will continue to have a dominant role in basic research. The third element of our broad policy—that support will come through a multiplicity of agencies—is not so certain. There continues to be serious talk of an umbrella-like Department of Science. Personally, I am convinced that multiple-agency support will continue.

A historian may quarrel with my analysis of the U.S. decision-making procedures. He would not quarrel with the visible consequences. As we all know, the past 20 years have witnessed a buildup of major proportions in federal support to the universities. Very large amounts of federal funds have been granted under the rubric "research," particularly for efforts in the natural sciences, mathematics, and engineering. Support for the social sciences has been far from negligible, and, very recently, small amounts of support for the arts and humanities have come from the new foundation established for this purpose, but the principal federal research support to universities has been in science and engineering.

During this same period, fellowship support for graduate training by the federal government has also built up rapidly. Some of this has come from science-oriented agencies like NSF and NIH. But other and broader fellowship programs have been started in the Office of Education, notably the National Defense Education Act fellowship program. Paralleling these teaching and research funds has been major support to the universities for new construction—again, particularly for facilities for graduate study and research. And, finally, there has been substantial support for special education programs.

It is often charged that this federal support is unbalanced in its strong emphasis on science and engineering, and this charge has considerable justification. On the other hand, one must give the federal government very great credit indeed for two things. One is the very rapid rate at which support to the universities was increased. The second is the enlightened and flexible characteristics of the programs that were developed.

A New Situation

With all of this as background, the exceedingly important fact which we now face is that the growth of federal support for teaching and research in the universities has halted and the total support has perhaps even started to recede. This fact has been sharply dramatized by the necessity for NSF to put ceilings on university expenditures for the current year, ceilings which effectively lead to cuts of 20 to 30 percent in planned expenditures in the universities. Smaller but nevertheless real cuts have been made by NIH and other important support agencies. Clearly, we face a new situation. It is a situation which is doubly ominous—ominous in its immediate effects and in its longer-range implications. This is a matter of particular concern when put in juxtaposition with the fact that both total enrollment and graduate enrollment in universities continue to go upward. Even a constant level of support from the federal agencies will thus lead to diminishing support per student involved.

That these changes have been accompanied by increased signs of an overall public disaffection with science and science education is also ominous. To say that there is an anti-intellectual tendency in Washington and perhaps also in the country may be too strong, but at the least there is a generalized doubt, on the part of the public, that science is useful, and concern as to whether science merits the comparatively high degree of support that it has had in the recent past. Some of these negative analyses are reinforced by a parallel disaffection with the conduct of our universities. This has many facets, including reaction to student rebellions and reaction to anti-Vietnam demonstrations of one sort or another. But even thoughtful people are increasingly concerned about the relevance of many of the universities' activities to the nation's problems, particularly to such critical problems as preservation of our environment and racial justice.

A dedicated university scientist and teacher is particularly startled to find evidences of general disaffection just at a time when he believes things are going exceedingly well. In many ways he is right in this belief. By any reasonable standards, scientific progress in the United States is in excellent shape. To say that we lead the world in science and mathematics is a truism. It is also true that in our laboratories, and specifically in the universities, we have good, generally modern, facilities for research. And finally, on the question of adequacy of support for our graduate students, we can honestly say that considerable, if not always outstanding, support is available to almost all of them.

But at the same time that the university scientist makes this somewhat complacent analysis he must hasten to admit that the universities, and specifically the science programs within the universities, have a good many problems, some of them exceedingly serious. Within the traditional science fields there continue to be enormous pressures toward expansion. The total student body in the universities grows, and the number of undergraduate and graduate students in the standard fields of science continues to increase. New teaching and research facilities are needed for these students. Research is expensive, graduate training is expensive, and both clearly are going to remain expensive. Furthermore, there are steady pressures for setting up new programs in science and engineering. Thus, universities suddenly find that an important field of study called computer science is in their midst and needs support. New interdisciplinary efforts—for example, between biology and the physical sciences—are growing and also need support.

It is this strong sense of continued pressures which leads to the feelings of beleaguerment and dismay which so many of us share. At the individual-university level we know full well that we cannot stand still. If we do not build new programs and expand the best of our old ones, we are certain to regress. At the national level, this same feeling exists with respect to total research effort. We live in an age of technology, and in every direction the need for more and better science and more and better technology is upon us. If we are to solve our problems and avoid creating new ones, we must continue to produce research, and it had better be good research. Given this rather grim overall picture, we are forced to ask, What can we ourselves do to help obtain the support we all know our programs need?

Suggestions

A first and important answer is that there is no single solution which, if successful, will solve all our problems. The problems are a complex mixture of

internal university problems and problems of external relations, problems of preserving old programs and placing adequate emphasis on new ones. Because of this complexity we can be sure that there is no grand answer to our dilemma; there are only many partial answers. Each of us will have his own list of things to be done. I shall name several which seem important to me.

1) In our analyses and discussions we in the universities must put first emphasis on the university as an *educational institution.* Correspondingly, we must emphasize the kinds of support that the educational programs of the university need. In my view, a number of items have conspired to lead to more emphasis on research in universities, and more visibility of the research efforts, than the facts have ever warranted. Thus, the accident that much of our support comes from mission-oriented agencies, which necessarily place little or no explicit emphasis on the educational parts of the programs, has surely been a major factor. So, also, has been the desire of support groups for explicit answers and clear indications of research progress. Education, unfortunately, lends itself neither to easy analysis nor to spectacular measures of new progress. About all we can measure is the number of students we turn out, with little or no possibility of analyzing the depth of their training or the relevance of that training to the world they go into.

But the fact remains that universities are, first and foremost, educational institutions, and we must increasingly stress the fact that a major fraction of the support we ask for and need is for educational programs, most notably for the programs of graduate training. One consequence of this, I am convinced, is that we must increasingly press the support agencies having responsibility for education, such as the Office of Education and the National Science Foundation, to recognize the need to support universities on the basis of their education efforts. It is, I think, a sign of the times, and a very good sign, that a recent bill introduced by Congressman Fraser of Minnesota is entitled the Graduate Education Act of 1969, and calls for support to universities according to the number of Ph.D. degrees they have awarded in the past 3 years. Of equal interest is the fact that Congressman Fraser was assisted by five University of Minnesota professors in drafting his bill.

A related problem to which we in universities must give more thought is that of education at the postdoctoral level. We are deeply involved in this, but we have not yet developed the educational justification for it to anything like the depth to which we have developed justification for graduate training. If we wish this sort of education to continue as a major part of our work, we must be clear in our minds, and persuasive with others, as to what it is and where it fits into an overall university program.

2) We must stress and document the synergistic aspects of the linkage between teaching and research which so notably characterize the U.S. university. University people are themselves strongly committed to the belief that teaching and research are mutually helpful. At the same time, I do not think we have made our case to the degree we can and should. Furthermore, we must make our case at at least two, and perhaps three, levels. We must give clear and persuasive answers to those who ask why participation in research is considered the best kind of graduate training. Why, specifically, is a research apprenticeship the best means of training a student at this stage in his career? We should make the same sort of analysis for postdoctoral education.

I think, however, that we must make, with equal force, a case for research as an increasingly useful component of undergraduate training, and, along with this, must explain why the conduct of research makes professors better, more persuasive teachers.

3) We must be more explicit about the importance of basic research to our nation's progress. All of us have talked about the importance of basic research to technology. Unfortunately, we are all to some degree inclined to give the illustration of Michael Faraday and stop there. To put it bluntly, the whole basic research establishment is vulnerable to the cynical but wholly understandable question, "What have you done for me lately?" I think we must try to answer this question. We must tell why the basic research which we are now doing is needed, and what social benefits it relates to. We must do our best to forecast the trends of technology and the kinds of basic research that are broadly relevant to them. Since scientists are not, in my opinion, very good forecasters, our answers may not satisfy even ourselves, but still we must try.

As for the question "To whom should we communicate?" the reply is, "To everybody." We must tell our story in a way that the general public understands and appreciates. Much more specifically, we must focus our efforts on those groups that have been charged to concern themselves with the progress of education and of science. This especially means the legislative bodies at the federal and state levels. The old injunction "Tell it to your congressman" is precisely applicable.

In stressing the urgent importance of presenting the university needs and accomplishments, I am not simply saying that we in universities must become an all-out political pressure group. Perhaps we shall turn out to be partly that, whether we like it or not, but surely the first responsibility we must accept is that of telling our story thoughtfully and, to the extent possible, objectively. We *know* that science is important and that science education is essential. This is the case we must develop.

4) We must do everything possible to make our university programs of teaching and research as effective and as efficient as possible. I still recall the sharp comments an industrialist once made at a large meeting of the President's Science Advisory Committee in discussing costs of graduate training and research in universities. Noting that the costs per student trained had been rising steadily for the past 30 years, he said, "Universities are the only group that I know of in the whole United States economy where the costs per unit operation have been steadily rising. If you were a component of my industry I would probably call in your management and ask for greater efficiency, and if I didn't see some signs of it pretty rapidly I would fire them and hire a new crowd." This may sound overdrawn and silly, but it underlines a concern to which we must address ourselves.

To take a very large and specific problem, can we justify our exclusive emphasis on research apprenticeship as the path to advanced degrees? That such apprenticeship should be the path to our highest degree, the Ph.D., is, I think, something on which we all agree, but we know this is an expensive, time-consuming procedure. Are there alternatives which produce useful professionals but which are less costly overall? I doubt if we are giving adequate attention to this sort of efficiency.

To consider a related point, we must surely do everything possible in our universities to utilize our research equip-

ment as efficiently, and to teach our students as effectively, as we can. I am uneasy about analyzing education from the standpoint of efficiency, in the conventional meaning of the term. But surely this conventional meaning does apply to many of our research activities, particularly to our use of expensive or scarce equipment and facilities.

It is also important that we search for collaborative procedures among our sister universities to try to hold costs down. Cornell, for example, is exploring the possibility of collaborative efforts to share library resources with a half-dozen nearby universities. As scientists and educators we know of other areas that are comparably expensive and equally open to collaboration—for example, further centralization of computer equipment. Needless to say, not every effort toward collaboration will succeed, and not every one of them will save money, but we probably must try them all.

5) Scientists and engineers in universities must search for ways whereby we can participate in the applied research programs which link to the great sociotechnologic problems that we all see on the horizon. Not all of us can usefully contribute to the solution of problems of urban redevelopment or of air and water pollution, but some of us can, and probably we all should seek for possibilities. Most of these problems are complex and difficult and require interdisciplinary efforts in which progress will depend only partially on applied science and perhaps even less on basic science. But to the degree that the problems are science-based and to the degree that we, as citizens, recognize their importance, we should search for the places where we can help.

In the search, we may have to address ourselves much more sharply to the overall effectiveness of the university programs in these fields of applied research and sociotechnologic improvement. I think our record of accomplishment in these areas is not very good, especially where interdisciplinary actions are involved. Since I strongly suspect that there will be increased national emphasis in these areas, the universities may need to analyze and perhaps modify their procedures. Thus it may be that we need a much closer coupling to the governmental and industrial laboratories of applied research that will probably be charged with the action programs.

6) Before I turn to my final suggestion let me recall the first time that C. K. Ingold, of University College, London, came to Cornell as a visiting lecturer. At a large reception for him the somewhat ebullient wife of Cornell's dean was pressing Ingold as to why he had been willing to come to Cornell. Carried away by her enthusiasm she asked, "What persuaded you to come here? Wasn't it that you were impressed by the possibility of passing on your knowledge to a new group of students in a new land? Didn't the thought of communication among nations and need for international friendship loom large in your decision to come to Cornell? Wasn't it of enormous importance that you could be of service to such a large and different body of students?" To all of this Ingold nodded, saying, "Yes, yes, of course. And then," he added, "there was the money."

And this is, of course, our situation. Whatever else we have in the way of public understanding of our programs, the universities need money to support our students and update our facilities. I am convinced that most of this money must continue to come from federal agencies, and this is why we must work vigorously with the relevant congressional committees to persuade them of the importance of the university programs. We must persuade the Office of Education to take additional responsibility for higher education and especially for graduate training. We must attempt to get something like the Fraser bill enacted, and we must see to it that the National Science Foundation is increasingly well supported.

However, we must face the fact that, as of now, federal funds have leveled off and will probably increase only slowly at best. Hence we must look for other sources of funds to support our university teaching and research programs. One such source is the state and local governments. They have traditionally supported education, and they should be sympathetic to the serious needs of the universities. They must be persuaded that what the universities are doing is important, and that the way the universities are doing it is sensible and efficient.

In many of our searches for support for new programs and for better ways to do old jobs, we can turn to the foundations. They have always been a source of support for universities and, with continued effort on our part, should continue to be.

Finally, those of us who are chemists return to a source of support which we have long enjoyed and which we have perhaps neglected in our recent love affair with the federal government. I mean, of course, the chemical industry. It is the great good fortune of chemists that they have had such close ties with an industry that has looked to universities for much of its basic research and has depended on universities for a continuing supply of trained professional manpower. There are many pluses on both sides for a closer linkage between university scientists and the chemical industry. Each side can contribute toward analyzing new needs and foreseeing new directions. Industry can tell universities more clearly and carefully what is in store for the students who will be coming to the chemical industry, and can thereby help in the training process. Universities, in turn, can broaden their teaching responsibilities and play, as I personally think they should, a larger role in the continued updating of the older professional people in the industrial establishment. Industry and the university establishment can be closer and more mutually supportive in the conduct of basic research. Among the many likely consequences of these firmer links is one which relates directly to our current discussion—namely, more funds to the universities for their teaching and research programs.

You may ask, Is it reasonable to expect greatly increased university support from industry? Perhaps the best answer I can give is to say that there appears to be one country in which very large-scale industrial support does occur, and that is West Germany. According to the 1965 National Academy of Sciences report on Chemistry, even in 1960 the level of West German support for basic research from the chemical industry was the equivalent of $17 million per year. This is roughly the amount which NSF has allotted to chemistry research in the current year—in other words, a very substantial contribution. Perhaps our motto should be: If the German scientists can do it, so can we!

Summary

Let me conclude by saying that adequate support of science research and education in universities is a serious problem and one which demands the most imaginative efforts of the university scientists. I have tried to suggest a few things to do. There are surely many others. Perhaps the proper concluding injunction is, time is wasting and we had better get cracking.