Epilogue

In the foregoing account I have deliberately pursued a single line of thought, neglecting both parallel developments in other laboratories and work performed in my own laboratory in which I didn't directly participate. A few of these omissions I feel obliged to repair.

Several people studied breakage of DNA by shear before we did. Davison (*20*) first noticed the extreme fragility of very long DNA molecules, and he and Levinthal (*21*) pursued the theory of breakage. However, we first noticed stepwise breakage at critical rates of shear. That observation was needed both to substantiate theory and to complete our evidence for molecular homogeneity.

Davison *et al.* (*22*) also showed that particles of phage T2 contain single DNA molecules, though they didn't attempt direct measurements of molecular weight.

Physical studies of DNA had of course been under way for some years before analysis of virus particles began. For instance, Doty, McGill, and Rice (*23*) had observed a relation equivalent to our Eq. 1, containing the exponent 0.37. Their data covered a range of molecular weights below seven million. Larger molecules were not known at the time of their work and could not have been studied by the existing methods anyway.

Our work on sedimentation of DNA in sucrose would have been considerably eased if we had known of the earlier work on sedimentation of enzymes by Martin and Ames (*24*).

The first example of a circular DNA (*25*), as well as the first evidence for one DNA molecule per phage particle (*26*), came from Sinsheimer's work with phage ϕX174. Its DNA comes in single strands that weigh only 1.7 million daltons, which is small enough to permit light-scattering measurements.

Elizabeth Burgi (*18*) demonstrated reductions of molecular weight of DNA in deletion mutants of phage λ already shown by G. Kellenberger *et al.* (*27*) to contain reduced amounts of DNA per phage particle.

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Changing Dynamics in Research and Development

Hugo Thiemann

A tremendous responsibility has fallen upon humanity now that it is, in the words of the German philosopher Georg Picht (*1*), "generating its own future." This situation, unique in the history of the world, is a direct consequence of research and development activity linked to technology of such power that the very existence of humanity is in danger. The earth is becoming such a small planet, and all actions are becoming so interdependent, that we may envision the world as a single, but tremendously complex system. Scientific attempts are being made to understand the critical state of humanity, the imbalances already created, and the systemic character of the problems humanity is facing as it looks toward its future evolution.

All this has important implications for the research and development community and for the individual scientist. On looking into the early history of science (*2*) one becomes aware that the personality of the scientist has not greatly changed. The special characteristics that distinguish him from the nonscientist were evident from the earliest days of science. The scientist is driven by a tremendous inner force of curiosity in his quest toward understanding what he observes. He often risks his existence when trying to overcome obstacles, and is not discouraged by failures. He has often to be stubborn to maintain faith in his goals. However, the tremendous worldwide changes that have occurred in this century have markedly changed his position as an individual, have drastically altered the role he plays in society, and have greatly increased his numbers. At the beginning of the 19th century the number of scientists in the exact sciences was very small, perhaps less than 10^{-5} of a nation's total population. The scientist was a rare species of human being, primarily active in the university. He was honored and granted special privileges. That science, as such, is good

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was a belief then deeply held by a large part of society. The scientist, very little understood by society, developed his own way of thinking. Society in general believed that all the knowledge he acquired would be useful, and that he should have total freedom to concentrate on whatever field attracted him and gave him personal satisfaction.

In recent years this attitude has been changing. Uncritical belief in science per se seems to have vanished. Most populations in the industrialized world are going through a *crise de conscience*. Even the belief that science is essential for economic growth seems to be shaken. For the scientist, a kind of thunderstorm is developing. Not only is the attitude of society changing but the community of scientists engaged in research and development has also changed, dramatically so. Science has become the main tool for changing and improving the conditions of man's existence, hence a considerable flow of funds has been channeled into the activity of scientists in recent years. The scientist, instead of working as an individual, now works as a member of a group. In today's population of research scientists we find a considerable number of people who might be characterized as scientific workers. These scientists are essential in all research laboratories. They work, by and large, according to specific instructions, often building and handling very sophisticated equipment. But they differ from the scientist who feels himself set apart by his creative power and who invents new tools according to his own "guidance system." Thus the research and development community has become both different and very large.

It continues to grow, for still another reason.

Interaction of Science and Society

As René Dubos puts it (*3*), "our ancestors mobilized science to master nature and to create wealth through technology"; it looks today as if we need more science in order to master the consequences of technology. So much disorder has been created in the environment as a consequence of scientific work that a new and complex problem is arising in the United States and the countries of Western Europe—the interaction of science and society. We may say that the scientific community at large has been capable mainly of finding *how* to reach a specific result. The economic community, however, is becoming more and more interested in *what* the research projects should be. The philosophers, and also some advanced scientists today, are steadily asking *why* research projects are being formulated.

The size of the research and development community is to be gauged not so much by the number of research projects being pursued as by the absolute dimension of specific undertakings —for instance, the development of nuclear energy and, in particular, of atomic weapons. The size and nature of these research and development projects is such that the world of the future will be dramatically influenced by them. Decisions on "what to undertake" are therefore shaping tomorrow's world. Science is becoming a political power. The scientist is no longer an independent, free individual, concerned solely with what he can find. Now he is concerned with what he ought to do; society influences him, by deciding upon financial appropriations. Therefore, a new and difficult decision-making process is developing, under the tag of "science policy." The scientific community is faced with these new elements; they change the established attitude of the scientist, who now finds himself in an insecure situation. Many technological forecasting studies are being undertaken, and people who act at the policy-making level are looking desperately for a basis on which to decide priorities.

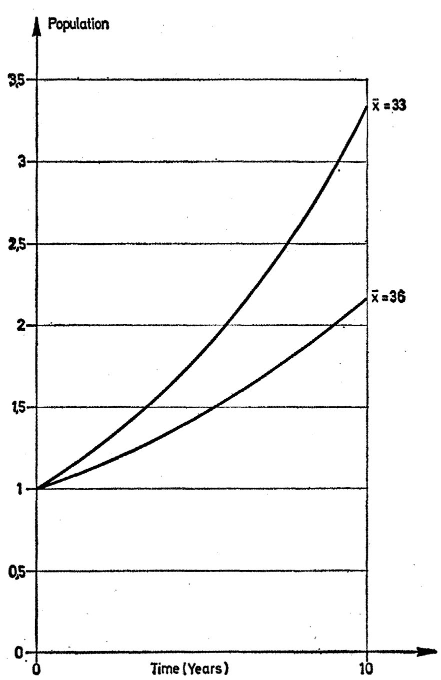

Fig. 1. Increase (in percentages) of the population of the research and development community plotted against time (in years) for average ages of 33 and 36 years, respectively. The individual's age on entering the community is assumed to be 25 years, and his age on retiring from it, 65 years.

Growth of the Research and Development Community

If we take a look at national economic goals, we see that all countries are planning for growth. So are most of the private companies in the industrial world. There seems to be a kind of law: either grow or die! Is the problem similar for the research and development community? Here we have to consider growth in numbers of people and growth in funds separately. It has been shown that, since statistics have been available, the number of professionals in science has increased exponentially, with a doubling time of approximately 15 years (*4*). Of course not all scientists are active in research and development, but very many are. We may analyze some of the factors which govern the growth of the research and development community.

In earlier days the rate of growth of the community was determined by the personal interests of scientists, whose numbers were relatively small. Later, the specific normative process for attaining practical goals became more important. Nowadays we observe a new factor, due to the large number of people who are active in research and development. It seems that a vigorous research community keeps its *average age* constant. Experience has shown that this average age should be rather low, certainly below 40—for example, 33 to 36! This fact may be related to the fact that creativity is associated with youth, but it is probably related even more to the rapid introduction of new research tools. The computer is an example. Young people use it today much as the older generation used the slide rule, whereas older staff members seem reluctant to use it in daily work.

My associates and I are therefore studying how a community of people with a given average age X is growing. Youngsters enter it at a certain age—say, at X_e years of average age—and older workers retire from it at X_s years of average age. If we maintain a constant average age of X years, the population grows in time according to an exponential law of the type e^{Kt}. The relation which links the growth K (increase of relative number of people per year) of the community to the average age and to the entering and retiring ages can be expressed as follows:

$$\overline{X} = X_s + \frac{1}{K} = \frac{(X_s - X_e)e^{K(X_s - X_e)}}{e^{K(X_s - X_e)} - 1}$$

To take an example, let us consider the case in which the average age $\overline{X}$ is 33 and then 36, the entering age X_e is 25, and the retiring age X_s is 65 (see Fig. 1). It is obvious how fast such a community grows! If it did not grow, the average age in our example would rise to

$$\frac{65+25}{2} = 45 \text{ years}$$

From experience, we know that a value of 45 years is much too high. Consider now the growth of a population in which the retiring age X_s is a variable. In Figs. 2 and 3, the cases of $X_e = 25$ and of $\overline{X} = 33$ and 36, respectively, are shown.

To take an example, the rate of growth of the population of the United States has been approximately 1.5 percent per year over the past 10 years. It is a known fact that the population in research and development has grown more rapidly than the total population has over the past 10 years; the rate of growth has been about 0.5 percent per year (*5*). If, in order to achieve a long-range stabilization, we assume that the growth of the research and development community is not greater than the growth of the total population, we obtain, in the case of an average age of 33 for the research and development community, a retiring age of 41.5 and, in the case of an average age of 36, a retiring age of 49.

We are learning that, for a research and development community of the size of the present one (expressed as a percentage of the total population), a move to other professions has to take place at rather early ages. The situation must also be considered from the point of view of numbers of people. One can estimate the size of the research and development community in numbers of people from the total R & D costs and the average cost per member of the community (here "member" includes both scientists and supporting staff). With the figures for 1968 for the United States (total R & D expenditures, $26 billion; estimated cost per member of the research and development community, $20,000), one obtains 1.3×10^6 people. Published statistics show that this number is about the same as the number of production workers in the machine industry (with the exception of the electrical industry)—1371×10^6 production workers in 1967.

We may conclude that the research and development community keeps its average age and will defend its existence. The community already constitutes a considerable pressure group, comparable to a large labor force, and may be in a position to influence science policy in a significant manner. Indeed, the community may grow independently of its scientific or technical goal—an unusual new situation in research and development!

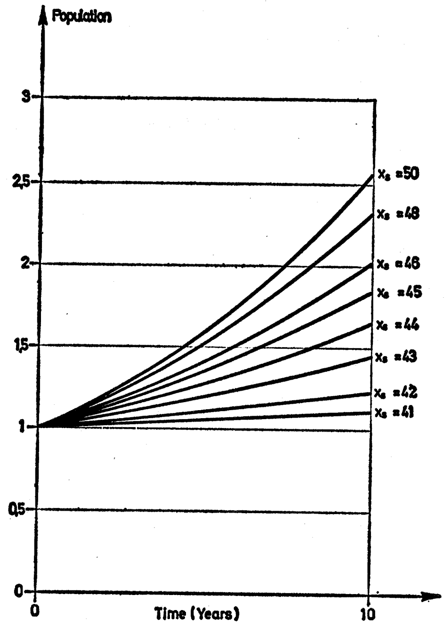

Fig. 2. Increase (in percentages) of the population of the research and development community plotted against time (in years) for a constant average age of 33 years, an age on entering the community of 25 years, and an age on retiring from it indicated by the parameter X_s.

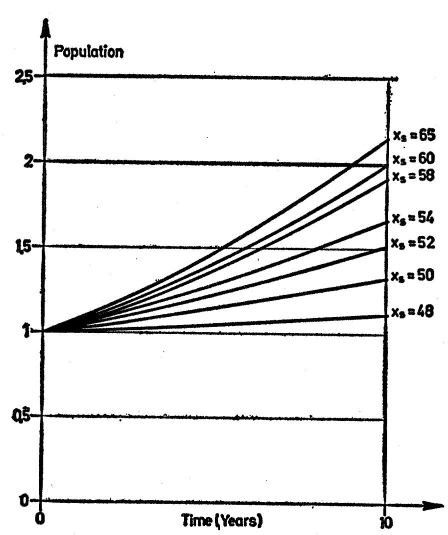

Fig. 3. Increase (in percentages) of the population of the research and development community plotted against time (in years) for a constant average age of 36 years, an age on entering the community of 25 years, and an age on retiring from it indicated by the parameter X_s.

As regards funding, the situation may be more drastic because the costs per capita in research and development are on the increase, due to the development and use of more sophisticated tools (as in nuclear research). It looks, however, as though saturation had been reached in the United States for total R & D expenditure (now around 3 percent of the gross national product). We may therefore be entering a phase of change. The research and development community is coming up against a barrier. In the past the projects defined as a function of specific needs called for research and development people; today, however, it looks as though research and development people may well ask for projects in order to survive.

The "Big Science Projects"

A new evolution started with the appearance of specific research and development goals for military purposes during World War II. The science community became polarized, by the technical problems and also by the direction of flow of funds. Also, an institutional change took place—namely, the appearance of many research laboratories not associated with universities. In many countries in more recent years, large government-owned institutions were created with very specific missions, especially in the field of nuclear energy. The importance of such large missions is illustrated by the fact that Atomic Energy Commission and space activities alone accounted for 41 percent of the total R & D expenditures in the United States in 1967. Many Western European countries, uneasy about the spectacular technological advances being made in the United States and their military implications, started to set up similar institutions, though from motives other than those that underlay the U.S. activities. The institutions thus created in these other countries are already facing difficult problems today, when their specific missions have been accomplished or superseded. Such institutions are now in the situation of needing new goals, with the populations of their research and development communities in no position to define them! This seems to be characteristic of the situation in many countries today. This is clearly a shift from deciding *how* to do research to deciding *what* research is to be done. Since the new goals may no longer be of a military nature, the problem will be one of defining new goals in a more complex environment, in which it is not clear who decides and who pays. The new situation is more difficult than the earlier one, because the goals are not mere copies of ventures already started by others. Research for determining essential goals is a new and difficult task, and one which is linked to the creation of new institutional structures and financial resources.

The big science projects in some countries of Western Europe led to the establishment of large laboratory complexes, huge testing facilities, and apparatus for handling large groups of people. The situation in certain institutions which were created for developing nuclear power is becoming critical as the original mission nears accomplishment. Symptoms of this kind are visible in various countries having large nuclear facilities, such as the United Kingdom, France, and those of the European Community.

These institutions, instead of producing important results, are now in a precarious situation, with their very survival in question. This may require a change of institutional structure, which is part of the government in many countries, or of international organizations such as the European Community. The possible new goals must be compatible with the established institutions. The shift from a small number of large projects to a large number of small projects, and their financing, often calls for types of people very different from those who are at present in the organization.

This situation is serious, also, from the point of view of education and the prospects of younger members of the research staff. It gives a false picture of the need for people: universities are increasing their facilities to satisfy a "need" for positions which do not really exist. This may lead to difficult social problems for young graduates.

A controversial picture is emerging. On the one hand we witness a kind of redundancy of research and development staff and facilities linked to a number of "big science projects" for which the motivation for financial support was created some time ago. On the other hand we observe tremendous problems that humanity will be facing in the future; these problems should be attacked, but there appears as yet to be insufficient motivation for making the necessary great efforts. It seems that nobody is frightened enough.

Research toward Research Goals

The problems outlined above concerning the research and development community could lead to different consequences. Either those who are active in research and development should change their profession at a rather young age (and such a solution would, in principle, bring the growth of the community into equilibrium with the total population growth), or the research and development community should find new important research goals. The first solution is very difficult to realize because of its social consequences, especially in those countries where the research and development population consists largely of government employees. As shown above, the large absolute number of people represents an important pressure group, and it is likely that this group will continue to grow. Therefore, a conversion into other research areas seems necessary.

Extensive studies will be required if such new subjects for research are to be wisely selected. Letting the established large government research institutions work for industry, in accordance with the present trend, may not be a stable solution because industry is in most cases not in a position either to finance such undertakings or to decide its own future goals. National efforts are often decided by considerations of prestige, and this does not afford a very stable solution. Government institutions perform the tasks set for them by the respective governments. A motivation could be the need to outline new possibilities for future industrial activities in fields in which today's industry is not able to do the necessary groundwork, in particular as regards long-term goals. On the other hand, government institutions could help to solve or to avoid future problems which befall society, and they would certainly not be attacked by private industry for doing so.

An important set of questions must be answered if future needs for a specific country are to be accurately perceived. Scientists have a new tool in the opportunity to study mathematical models of dynamic development, in which alternative approaches can be worked out in order to prepare the ground for sound decision-making. Such studies require close collaboration on the part of sociologists, econometricians, economists, and mathematicians. Nationalistic attitudes may lead to similar solutions in different countries, but it is hoped that differences in human and natural resources, climate, and other factors will lead to specific, different goals. The problems will perhaps lie more on the institutional side —in creation of the will, on the part of policy makers, to undertake such research projects; otherwise, funding will not be possible.

Science Policy

The need for growth despite the limitation of financial resources leads necessarily to the establishment of research policies. In most countries, national goals for research are not yet clearly perceivable, although considerable effort is being made to clarify the situation. The initiation of projects is done mainly by the research and development community itself. The outstanding scientist is sufficiently creative and intuitive not to need a science policy (*6*). Such policies could even smother his creativity or endanger a promising research environment. On the other hand, it may be that a science policy is part of the expression of the cultural mission of a civilized nation. In any case, a science policy is badly needed because of the large size of the research and development population relative to the population of true scientists. A choice of research efforts is unavoidable.

The problem is to define research avenues which give the scientists sufficient freedom of action. The necessary intervention should be mainly encouragement and considerable help, in the institutional sense, which will give scientists a certain security that will encourage sustained effort. Today research policies consist mainly in response to different pressure groups. It may be that this is the only true democratic means of arriving at a consensus.

Innovation

Innovation is a chain of different creative processes. It entails turning an invention into a successful practical result. It is an essential element in modern industrial activity. It is the expression of the pressure which is put on scientists today to achieve useful results. In consequence of the growth and the size of the research and development community, pressure is being increasingly put on scientists to produce practical results in a short time. Whether the outcome of such an evolution will be an exploitation of the willingness of society to accept an increasing number of innovations is not certain. We observe that a human community, an industrial group, or even a laboratory does not readily accept changes (*7*). Practical experience shows that industries which are developing thanks to technical innovations are reluctant to change their traditional ways and to accept obsolescence. It seems that pressure for greater practical effectiveness of research and development must be coupled with a change in attitude toward accepting innovations. Often the necessary institutional system for turning inventions into economic successes is lacking.

Global Problems

Science policies are considered mainly on a national level because the funds for their realization are provided by national governments. This limitation gives disproportionate emphasis to the so-called "prestige" projects. Science has no national boundaries, but research and development projects almost always have such boundaries. Is it not strange that private enterprises in different countries should have found ways of establishing international collaboration whereas governments cannot find ways of letting taxpayers' money cross frontiers? One may hope that a new institutional solution will be found which will do away with the difficulties of today's negotiations among countries. It may be that an international science foundation should be set up, inspired perhaps by the National Science Foundation in the United States. Such an organization should get financial resources from all the developed nations, irrespective of what the donor gets in return. Such an institution might really be able to support international research on the earth's atmosphere, on space, on pollution, on natural resources, and on other global problems.

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NEWS AND COMMENT

HEW: The Department That Lost Its Head

The Administration shake-up, which started in the Department of Health, Education, and Welfare (HEW) and culminated last week in the plan for a more potent concentration of management and budget authority in the White House, has defined more clearly than ever how President Nixon intends to wield Executive power.

At the same time, the flurry of firings and resignations at troubled HEW attests the new dimensions of difficulty faced by both politically appointed officials and career bureaucrats who administer federal social programs.

The changes have stimulated an orgy of interpretation, and much speculation has been expended on the translation of Robert Finch from secretary of HEW to presidential adviser. One popular thesis is that Finch the moderate found himself so frequently at odds with White House positions affecting his domain that, because of personal loyalty to the President, he ultimately decided he would rather switch than fight.

Another view is that Finch was unsuited by temperament and talents to mastering the HEW hydra and that his old friend the President rescued him from a situation that was wearing on Finch's reputation and on his nerves. Nixon accentuated the positive in welcoming Finch to the White House inner circle, but administrative performance has been faulted bluntly by Nixon lieutenants in the case of two notable firings of recent weeks, those of Commissioner of Education James E. Allen, Jr., and National Institute of Mental Health (NIMH) director Stanley F. Yolles. There was ambiguity as well as bitterness in both firings, since Allen had publicly questioned United States actions in Cambodia and had earlier expressed views on several educational issues which diverged from those of his Administration superiors. Yolles had been similarly outspoken (*Science*, 12 June 1970), and both men had complained about political interference with the operation of their agencies.

To depict Allen, a political appointee, and Yolles, a career official, as liberal martyrs, however, or to accept the simple verdict that they were bad managers from an Administration that contributed to their difficulties would be to ignore the rich complexity of HEW's inner politics and a new mood in the bureaucracy.

There was a time when bureaucrats in the Office of Education collected statistics and Public Health Service officers ran public hospitals and worked to prevent and control infectious diseases. Since the New Deal, and particularly