THE PROBLEM FROM THE STANDPOINT OF THE SCIENTIST AND TECHNICIAN

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In commenting on the topic which is the theme of this symposium from the point of view of the scientist and the engineer, it should perhaps be noted at once that the question of numerical shortages in these professions is somewhat alien to their typical attitude towards their professions. The typical scientist, and to some extent the engineer, seldom thinks in quantitative terms about the members of his profession. In spite of the trend towards team research and towards massive research programs involving highly organized groups, the scientist is even yet fundamentally a lone worker. His job is a highly personal one to him. As a consequence, the differences among scientists are more important than the similarities. These differences relate to personal competence, personal specializations, personal working habits and personal techniques. The scientists is much more inclined to think in terms of individuals and especially the outstanding contributors than in mass or quantitative terms. The scientist knows too well that the top 100 scientists can outproduce the next 100 by a substantial factor. Hence, he is much more conditioned to worrying about quality than he is about quantity, and this is particularly true about the leadership among the scientists.

It seems important to begin this discussion in this way because the question may well be whether one should look at this matter as a statistical problem in which one seeks the most accurate means of relating our needs or our demands for personnel in these categories against supply or whether one examines the evolution of technology as a process of the whole.

In approaching the question in this fashion I assume we are not mainly concerned with the instantaneous relationship between supply and demand as of January 1, 1959, about which one can not affect the emerging discrepancies too greatly, but about the situation which would appear to be confronting us some time in the future when those now at various stages in the educational process emerge to play their parts in the evaluation of science and in the maintenance and development of our technology. The significance of this question lies mostly in its future implications.

To the scientist, the process of the evaluation of scientific discovery is more a natural point of departure. To the economist the ebb and flow of economic forces play a more dominant role in his thinking and no doubt this point of departure leads to the statistical approach. Neither of these is adequate alone in understanding the forward movement of technology and in deducing what the future may hold in respect to the relationship between our future supply and our future needs for scientists and engineers.

One thing seems clear. As a nation we have moved definitely far away from the pre-world War II position in which the beneficênt processes of our society were dependent upon to supply adequate personnel resources in these fields. Since World War II we have moved far toward subsidies for individuals and institutions by private and public moneys to stimulate the flow of personnel in these categories. It is becoming more imperative that we somehow shall be able to understand the underlying dynamics of both supply and demand. When we attempt to buy up the difference between supply and demand we are more likely to be concerned about quantitative evaluation of the deficit between the two.

The scientist is, as indicated above, more likely to be aware of the dynamic character of scientific discovery not only in leading to economic exploitation of the new discovery but in the uncovering of new areas of scientific investigation. The rich discoveries of the Elizabethan era probably resulted from no discernible economic motivation but did lead to the evaluation of the basic structure of science. The discoveries of Oersted and the subsequent invention of the motor and the dynamo probably were events in which economic motivations were inconspicuous. Yet modern technology is, to a large extent, based on these two instruments. The electrical engineers and technicians needed in their production, use, and improvement are legion.

Similarly the vacuum tube, the vacuum pump, the processes of fission and fusion, and innumerable others are similarly cases in point. Additional examples from every field of science can be adduced.

None of these developments was unaffected in their rate of development by economic considerations and more recently by political considerations. But each possessed a dynamic impetus intrinsic to itself. The mere existence of a new discovery opens up areas of discovery, on the one hand, and opportunities for application to commerce and industry, on the other. Some of these latter opportunities are so attractive that exploitation occurs whether the economic climate is generally favorable or not.

Scientists are aware, too, of the insistent demands of a growing technology for information which has not yet been uncovered. This, too, is one of the underlying dynamic forces which contribute to the expansion of technology. In recent years this factor has been of growing importance as a factor. Examples are numerous. The petroleum industry has resorted to more and more scientific methods in petroleum exploration and in the processing of petroleum. Born of necessity the resulting information has had significance beyond the problems which gave rise to the new knowledge. High temperature metallurgy called for by the developments in nuclear technology and jet propulsion is another case in point. Similar cases abound in the mathematics of complex wave structures and supersonic shock waves, in the researches related to the major medical problems, in nuclear chemistry and a host of other fields.

One more consideration is becoming more insistent in its effect on the technological activities of our own country in particular, but on others as well. This is the regenerative phenomenon in which technological developments create technological problems which must be solved if our society and its scientific activities are not to choke themselves to death. Examples of this also abound and are more or less obvious on the face of events. Growth of population and of communities, of transportation, of communications, and all the phenomena of expansion present massive problems. The road network now evolving has made civil engineers a shortage category, but also presents intricate engineering problems in traffic control, in the design and structure of roads and a host of satellite problems of a social, economic and political nature, as well as a technological one. The growth of the information corpus presents new and massive problems in the storage, analysis and retrieval of information which again must rely on technology for their solutions. The logarithmic rate of increase in our demands on food, fiber, minerals, and water are foreshadowing problems in the supply of raw materials for our civilization, which will no doubt also grow logarithmically in their demands for scientific and technical effort and for appropriate personnel. We are even now changing from a "have" to a "have not" nation in respect to certain key commodities and raw materials essential to our industries, such as iron ore, and other metals. These shortages create the need for much research to reduce to the minimum our dependence on lines of supply which are vulnerable and may be in jeopardy at some future critical time.

This is by no means a catalog of the intrinsic factors which are inherent in science and its environment and which contribute to the expansionist tendencies of science. They should, however, indicate that these factors exist. It is quite apparent that they are powerful in the determination of the level of demand which will probably exist in the future. It should also be apparent that as yet there is no good statistical method of measuring them.

Any judgment amounting to a quantitative assessment of future manpower needs must find a way to grapple with these intrinsic dynamisms. They may be said to be those dynamic attributes of science which because scientific information exists, further technological efforts arise to utilize it.

More recently, two new motivations have arisen which lead substantially to increased activities in these fields. Because scientific information is now more generally considered to be of eventual benefit and economically profitable, industry has progressively become more research minded, and in increasing cases is willing to support research and development as a venture. Whether the research supported is basic or applied, programmatic or purely exploratory is less likely to be a matter of concern. The net effect is an increased stimulus to the growth of research laboratories, the creation of new knowledge, and hence the stimulation of the growth of technology as a whole, and consequently greater demands for personnel.

The other development is the extraordinary increase in the use of public money in the support of research and development, some of it obviously to serve specific military ends and purposes, some for the general welfare, some for the augmentation of the personnel resources and the increase in the rate of research itself.

These new developments create a new problem in the measurement of our future requirements because fundamentally the motivations in these two cases arise from policy judgments made by scientific laymen (in boards of directors, in the Government, both in Congress and the executive branch) and may at times be subject to fluctuations in response to gross economic and other changes in the climate of research support.

From what has been said, it might seem that the necessary conclusion is that the prediction of the course of technology and of science is a vain hope. It is true that we do not yet know how to assess the future impact of a given discovery, such as, for example, the practical use of semi-conductors in research and in industry. We know the transistor has been a powerful instrumentality and its applications are in their infancy. But no one in 1840 could have foreseen the manifold uses of the dynamo and the motor and their effect on later technology. No one could have foreseen the development of electronics following Dr. Forest's invention of the three electrode vacuum tube. No one could have foreseen the nuclear powered submarine following the discovery of nuclear disintegration.

And yet the growth of technology has a remarkable consistency when viewed as a whole historic movement. Whether one views one of its indices or another the characteristics are similar. The growth of technology and its underlying scientific structure is logarithmic. Even as far back as the days of steam power, and before electrical power took over, capital investment in steam power installations approximately doubled every ten years. The rate of employment of scientists and engineers has followed a logarithmic curve. The rate of production of persons trained in these technical specialties follows a similar curve. The production of persons trained to the doctorate in our country has increased roughly seven per cent per year for many decades, with interruptions only for major events such as World War II.

It seems likely that an adequate analysis of these past trend lines might lead to some understanding of the major determinants of growth, and of the limiting factors. These may turn out to be the per cent of the gross national product allocated to supporting certain types of scientific or technical activities. The limiting factor may be personnel. It may indeed be personnel of a special creative type. The role of a particular limiting factor may historically be more dominant at one period than at another.

Perhaps this discussion would not be complete without introducing one somewhat philosophical element. Assuming that in the long run the well-being of our scientific and technological effort will depend mostly on its cutting edge - its creative research scientists and its inventors and innovators - should every effort be made to search out, train and support such persons. Should we have conscious policy that we can never have too many of such persons actively engaged in the exploration on frontiers of science? Certain countries in the world appear to be following such a policy now. In our own country there has been a tendency to move in this direction. Obviously, the more we approximate such an accepted policy the more rapidly we are likely to accelerate the growth of our scientific knowledge and the technology on which it is based.

As one looks at this matter, therefore, in perspective both looking forward and backward in time, it would seem probable that our scientific evaluation and its technological associated development are from their very nature going to expand at least as rapidly as in the past. To a large extent this will be due to the explosive growth of scientific knowledge. It has recently been estimated that this knowledge increases presently at the rate to double every nine years. Not only will this momentum continue, but this knowledge itself will exert continuous pressure to increase activity in both basic and applied science.

The relatively new factors of political, economic and military interest should add impetus to this rate of development as they have since World War II especially.

The two emerging problems which will increasingly preoccupy attention and stimulate technical effort are, first, the problems arising from the increasing needs of our society for energy, raw materials, water and other resources, and second, the self-induced problems of an increasingly massive technology.

With respect to the first, there is in the long run no solution except through research. We shall increasingly be concerned with augmenting water resources, creating new substitute materials, new energy sources, and in more shrewdly using and controlling the use of what resources we do have.

In respect to the second, we shall be more concerned with storage, and retrieval of the massive flow of information arising from our scientific efforts in all fields of investigation. We shall be more concerned with problems of land use, highways and their effects, transportation channels, the effects of new technologies such as radiation hazards and high altitude and other novel environments, with relatively unsolved scientific problems of new areas of the globe, such as the tropics and the high latitudes, and with the new scientific problems associated with supersonic speeds, high temperature and low temperature, high pressure and other new realms of phenomena in which practical technology is now concerned. Most of these new problem areas are not linear but logarithmic in respect to the exploratory efforts which they will require.

One other facet of this matter should be discussed. This relates to the relationship of the individual in our society, to his scientific and technological environment and to his degree of familiarity with and understanding of the society in which he lives. This again points to the kind of education he receives in his school and college days.

It is quite possible for a person to live and be happy with no knowledge of science. But it is also possible to live and be happy with no knowledge of Greek and Latin, of the Renaissance, and even of the nature of modern society. But we generally assume that an intelligent citizen should be educated both for the sake of his own richer life, and so that he can function as a responsible citizen in a democracy. But we are by no means agreed as to the ingredients of his education.

This much is, however, obvious. The world into which young people emerged from their educational experience even as late as a generation ago differs from the present world perhaps more than the world of 1920 differed from that of many generations prior to that time. Assuming that education should be relevant to the world in which the student emerges, it would seem that education should have changed accordingly.

I presume that no one would seriously argue that it has. Most of the difference between life a generation or two ago and today is either technological in nature or caused by technology. Presumably the new importance of this aspect of life should have been apparent in a revised educational program.

There has been much concern over this matter recently as evidenced by massive studies aimed at improved curricula in certain sciences, legislation such as the Defense Education Act and discussions in the press and in other settings. However, most of the concern has been focused on pre-professional training.

The relevance of this point here is that probably no single change in our demands for personnel at home in the sciences could present such massive requirements for properly trained personnel as would a wholly adequate curriculum in the sciences at elementary, secondary, and college levels.

In summary, the scientist and the engineer, while becoming more conscious of the statistical aspects of the growing demands of our society for more persons trained in their disciplines, are much more conscious of the need for quality. They are primarily interested in the functioning of persons in their disciplines as individuals and are aware of the great difference between individuals in the contributions they may make. But they are aware also of the evolution of science and technology as a phenomenon with its own intrinsic pressures for expansion and growth. They are aware of the new and expanding role, and the increasing challenges to science lying just ahead. If science and technology are to continue to grow adequately to meet these challenges, undoubtedly the awareness of the layman of science must continue to grow. This is why scientists generally are becoming much more concerned over education, not only for prospective students in these specialties, but for the layman as well.