DOCUMENT RESUME

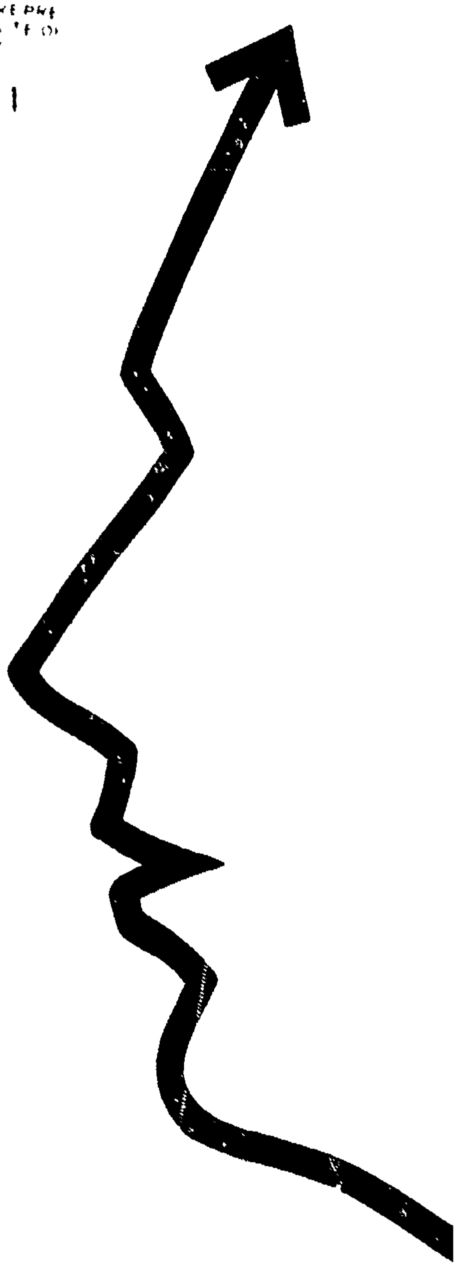
ED 099 181 SE 016 808

AUTHOR	Falk, Charles E.
TITLE	Scientific Human Resources: Profiles and Issues.
INSTITUTION	National Science Foundation, Washington, D.C.
REPORT NO	NSF-72-304
PUB DATE	72
NOTE	38p.
AVAILABLE FROM	Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402 (N51.2:5012, $0.25)
EDRS PRICE	MF-$0.75 HC-$1.85 PLUS POSTAGE
DESCRIPTORS	Career Planning; Careers; *Employment; Employment Projections; *Engineers; Manpower Needs; Manpower Utilization; Scientific Manpower; *Scientists

ABSTRACT

This publication is a report in which past trends and events relative to scientific manpower in the form of scientists and engineers are reviewed, the current status of the scientific manpower situation is described, and various assessments of possible future situations are compared. Within the last 25 years the situation has changed from one in which scientists and engineers had been able to pick the type of job desired and the geographic location to one of unemployment. The information contained in this report may be used as a sound, factual basis for future planning. (PEB)

SCIENTIFIC HUMAN RESOURCES: PROFILES AND ISSUES



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FOREWORD

Scientists and engineers are and will continue to be one of our most precious resources. They constitute the key element in our scientific and technological enterprise, which has so much to offer towards the improvement of the national welfare. At the present time, this professional manpower system is in a difficult transition period caused by changing national priorities and, at least temporarily, a balancing of supply and demand. This report, prepared by Dr. Charles E. Falk, Director of the Division of Science Resources Studies, constitutes a summary which reviews past trends and events, describes the current status, and compares various assessments made of possible future situations. As such, it represents a sound, factual basis for future planning.

H. Guyford Stever
Director
National Science Foundation

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INTRODUCTION

There is increasing concern over the current and future scientific* manpower situation in the United States. The type of concern, which is expressed at both the individual and institutional level, represents a relatively new phenomenon on the American scientific manpower scene—at least as far as the last 25-year period is concerned—in that it deals primarily with questions of oversupply. While there have been criticisms of the lack of national manpower planning in the area of science and technology, it should be recognized that attention to scientific manpower problems has been part of the national scene since the end of World War II which demonstrated that scientists could and should play a vital role in dealing with complex national technological endeavors. This recognition was intensified, with a broad base of public support, at the beginning of the Space Age in the late '50's and early '60's. At that time, and during the ensuing decade, major concern concentrated on the inadequacy of the supply of scientists. Expressions of this concern can be found in the "Seaborg Report"[1] issued in 1960 by the President's Science Advisory Committee, and the "Gilliland Report"[2] issued by the same Committee in late 1962. Congressional and Federal agency actions designed to remedy anticipated manpower shortages are well illustrated by the National Defense Education Act of 1958 and the initiation of traineeships and training grants by NASA in 1962 and the National Science Foundation in 1964.

However, the situation has changed rapidly and dramatically during the last few years. Scientists and engineers have experienced considerably greater difficulty in either finding work utilizing their specialized training or finding work at all. After a 20-year period of being almost able to pick the types of jobs desired and their geographic location, this change has come as a shock to those scientists who entered the labor market during this period and especially to the recent graduates who matriculated at a time when jobs were plentiful. Unemployment of scientists, miniscule up to the last 24-month period, has

*Throughout this paper, generic use will be made of the term "science" and its derivatives to indicate "science and engineering," including the social sciences.

also produced severe personal hardships for some individuals in all age groups. Because the problem has broad overtones related to the national welfare, manpower utilization, and educational policy, it has received considerable attention at every level of government, within professional societies, and among academic institutions and associations.

Scientific manpower problems and their solutions are especially difficult because of the long-time constants inherent in the dynamics of some parts of the system. Science students must make career decisions relatively early; many do so by the time they have completed one year of college, or even when they are still in high school. Consequently, the effects of career-choice changes on the supply of scientists are usually not felt until four to nine years after these changes have taken place. By the same token, once imbalances in the manpower pool have developed, it takes just about as long to achieve corrective actions, though within areas of science imbalances can sometimes be rectified through inter-field mobility. On the other hand, many of the factors controlling the utilization of scientific manpower change on a much more rapid scale. National decisions on the initiation, expansion, or reduction of broad programs can be implemented within a relatively short time as illustrated by the start of the space program in the late '50's, the recent reductions in space and defense programs, and the current, rapid evolution of national concern and programs dealing with major problems related to the quality of life in our society. The vitality of the economy, which also has a direct impact on the employment of scientists, can change markedly in a matter of months. Thus, with supply phenomena involving long-time constants and utilization capable of relatively rapid change, it is inevitable that we will experience periods of imbalance. One of the key challenges to national science manpower planning is the minimization of these periods of stress. While there may be a considerable degree of difficulty inherent in matching demand and supply, this should not be taken as a reason to forego better national science manpower planning. As a matter of fact, because of the long-time constants involved, both in the production of scientific manpower and in the development of the institutions which train them, the experience of the last two decades indicates clearly that more manpower planning than ever is required. Such planning must involve Federal, State, and local governments, the academic community, and the Nation's industrial enterprise.

Since we are clearly in the midst of a difficult transitional period, this report will summarize the current situation and the attempts which have been made to project future scientific manpower supply and utilization. However, before looking at the present and future, it is essential to review how we reached our present status because such knowledge will assist in the understanding of current problems and will provide the basis for projections into the future.

During the '60's, the relative interest among students in the natural sciences was maintained and stimulated by exciting intellectual developments in such fields as molecular biology, particle physics, astronomy, and spectacular technological feats such as the new space venture. The Nation as a whole encouraged these interests because of manpower needs generated by external challenges, namely those of space and defense. In addition, increased awareness and concern for societal problems contributed to the major relative increase in social science baccalaureates. The result was a rapid growth up to 1968 of R&D funding which in turn produced major expansions in academic and industrial institutions as well as greatly increased production and utilization of scientists (chart 1). Thus, between 1960 and 1970, industrial employment of natural scientists and engineers increased by about 35 percent[3] and baccalaureate production in science and engineering more than doubled (chart 2).[4] This growth in science baccalaureates was part of a broader increase in the number of total baccalaureate degrees granted which reflect (1) a rapidly growing national interest, including that of students, in higher education, (2) increased affluence in the United States, with real per capita income increasing by about 35 percent between 1959-69,[5] and (3) demographic factors such as the baby boom experienced after World War II (chart 3). Advanced degree growth rate was even greater—annual science master's production increased by a factor of 2.5 in 1960-70; and doctorates (excluding degrees such as M.D.), by 2.9.

The most rapid increase among science baccalaureate degrees in 1960-70 occurred in the field of social sciences, while engineering and the physical sciences maintained an almost constant level of baccalaureate production during the last five years (chart 4). However, the retention rate for advanced formal training for social science baccalaureates is relatively low.[4,6] Consequently, the growth rates for the annual number of master and doctorate degrees awarded in the social sciences were not very different from those in the natural sciences.

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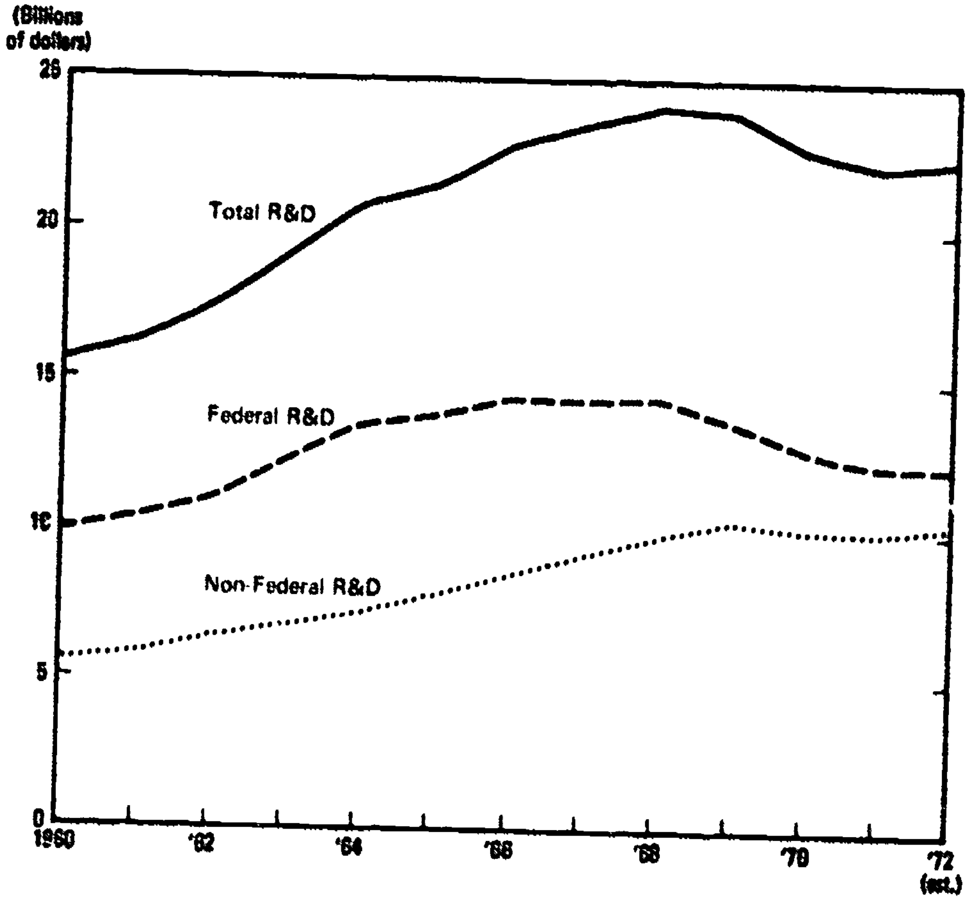
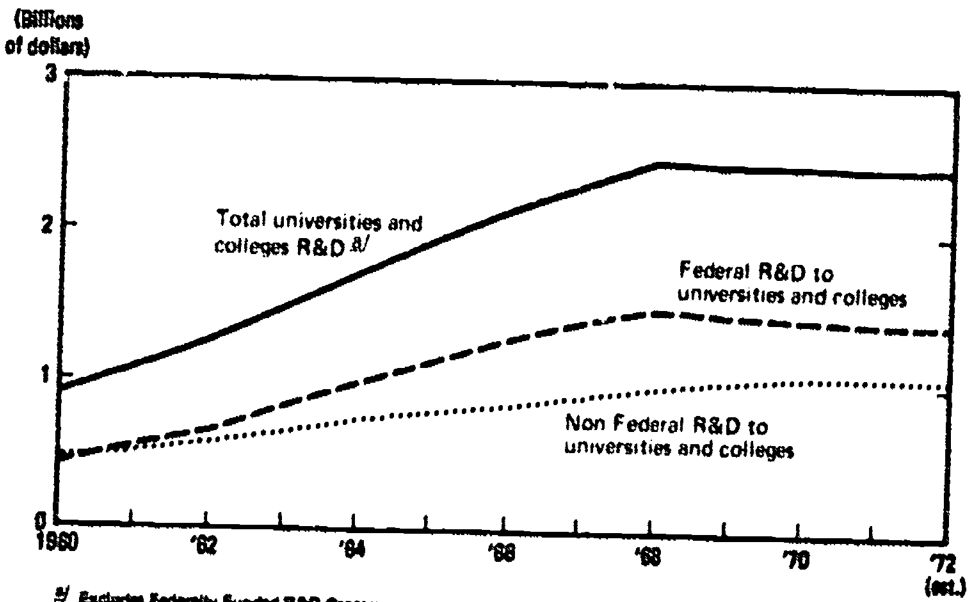
Chart 1. National R&D expenditures by source of funds, 1960-72. (Constant 1967 dollars)





a/ Excludes Federally Funded R&D Centers.
SOURCE: National Science Foundation

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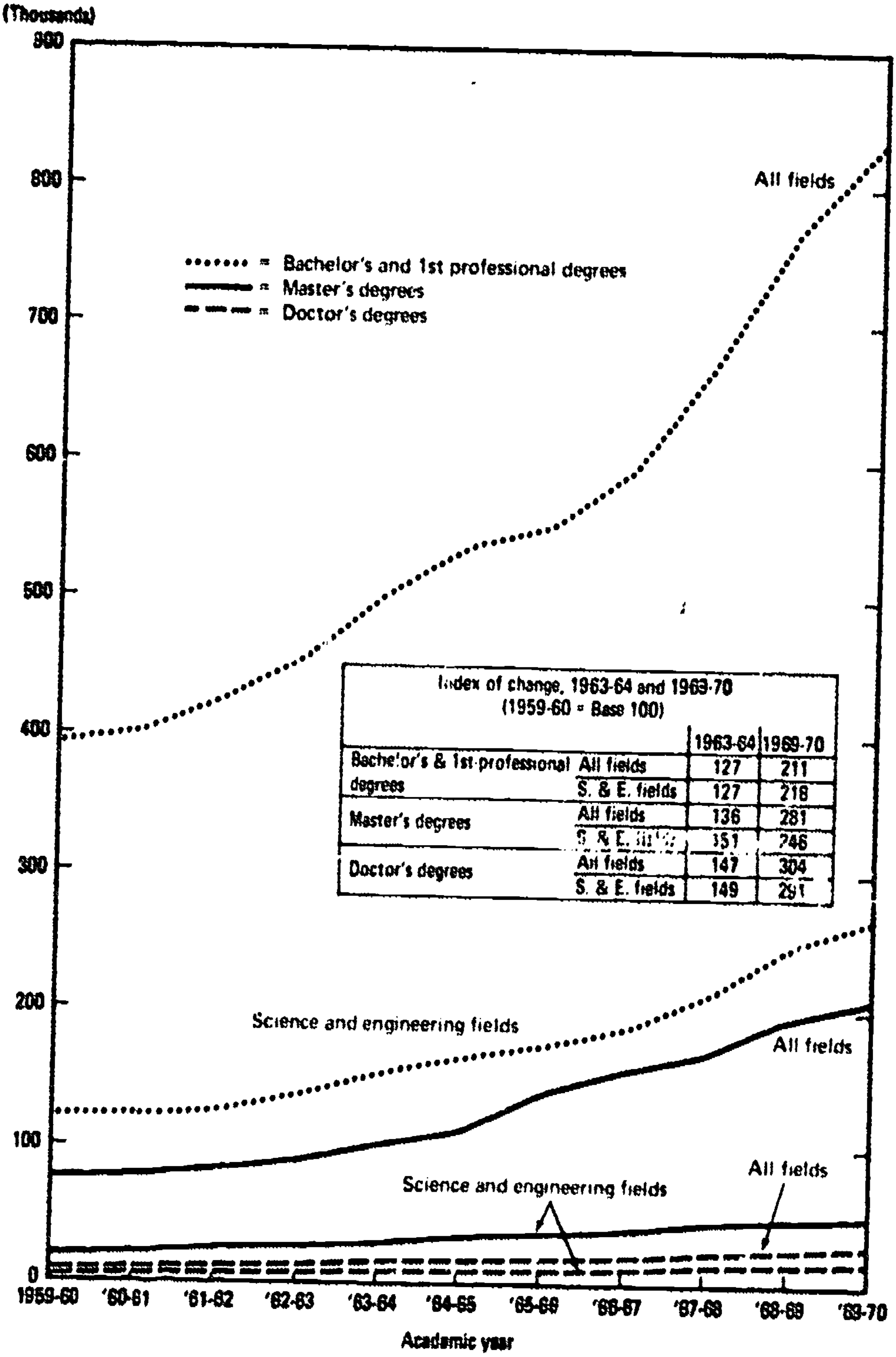
Chart 2. Degrees granted, all fields and science and engineering fields, by level of degree, 1959-60 to 1969-70.



Index of change, 1963-64 and 1969-70
(1959-60 = Base 100)

		1963-64	1969-70
Bachelor's & 1st-professional degrees	All fields	127	211
	S. & E. fields	127	218
Master's degrees	All fields	136	281
	S. & E. fields	151	246
Doctor's degrees	All fields	147	304
	S. & E. fields	149	291

SOURCE: U.S. Office of Education.

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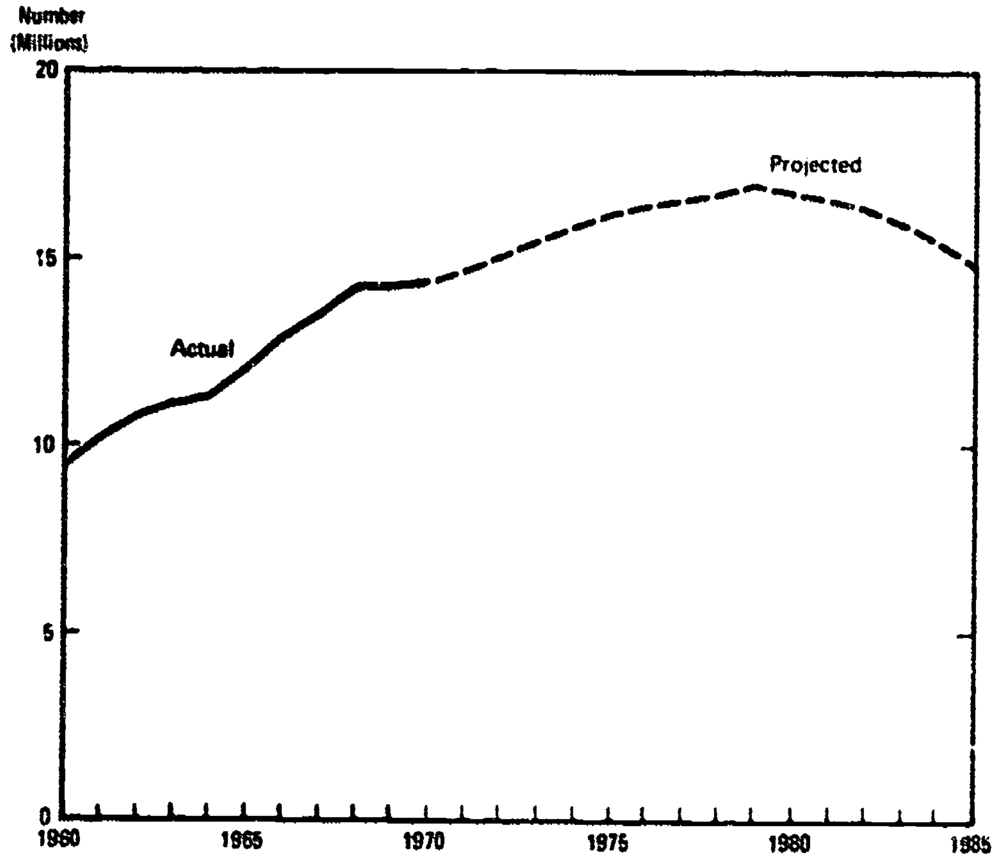
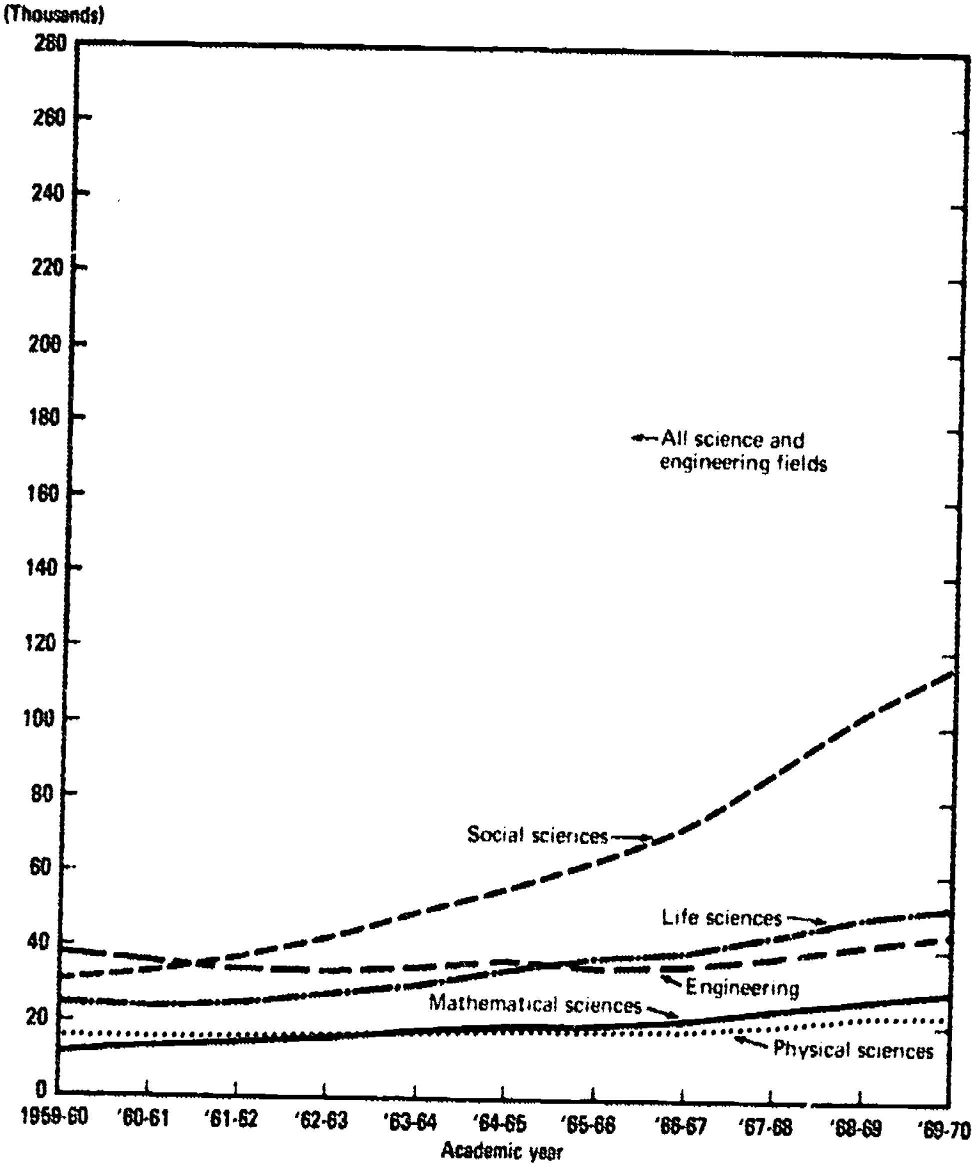
Chart 3. Number of 18 to 21 year olds, 1960 to 1985.



SOURCE Department of Commerce.

Chart 4. Bachelors and first-professional degrees in science and engineering, 1959-60 to 1969-70.



SOURCE: U.S. Office of Education.

THE PRESENT SITUATION

As a result of these sharp growths in academic degree award rates and some increases in the number of "upgraded" nondegree engineers necessitated by prevailing shortages, the total U.S. scientific and engineering work force increased from 1,160,000 in 1960 to just about 1,700,000 in 1969* (chart 5) and an estimated 1,750,000 in 1971. By 1969 the pool of Ph.D.'s had grown from about 90,000 to about 158,000 with the 1971 estimate amounting to about 185,000. This included an impressive increase by a factor of 3 in the number of engineering Ph.D.'s. This overall group of scientists and engineers was primarily employed by industry—70 percent—with government and academic institutions sharing the remainder. In contrast, the doctorates were primarily employed in universities and colleges, with 60 percent being located in academia. However, there was considerable variation among the various disciplines with almost 85 percent of the Ph.D.'s in mathematics located in academic institutions while only 40 percent of the physical scientists worked in universities and colleges.

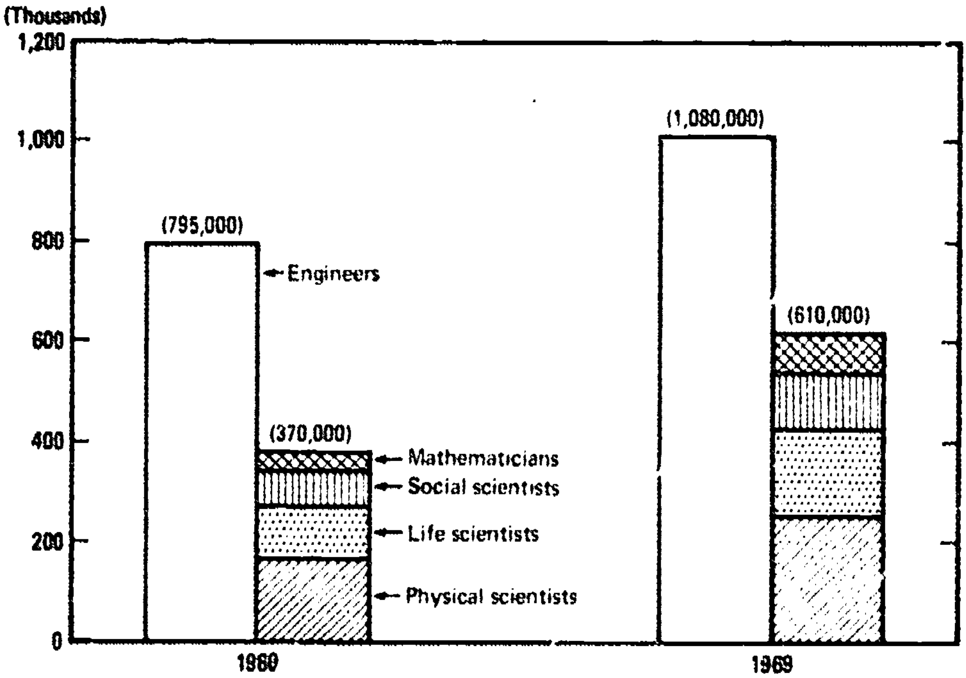
As for the distribution among types of activity, chart 6 shows that as expected only about one-third of non-Ph.D.'s are primarily involved in research and development, while about 50 percent of the doctorate group is concentrated in this activity.† Furthermore, there are again distinct differences among the various fields which become important for utilization projections.

In considering the present situation, it is also important to look at recent changes in student interests in science and technology because they have important implications with respect to the future supply. One of the earliest indicators is the career interest of first-time college students which has been studied by Astin, et al, of the American Council on Education.[7] These studies show that the fraction of these stu-

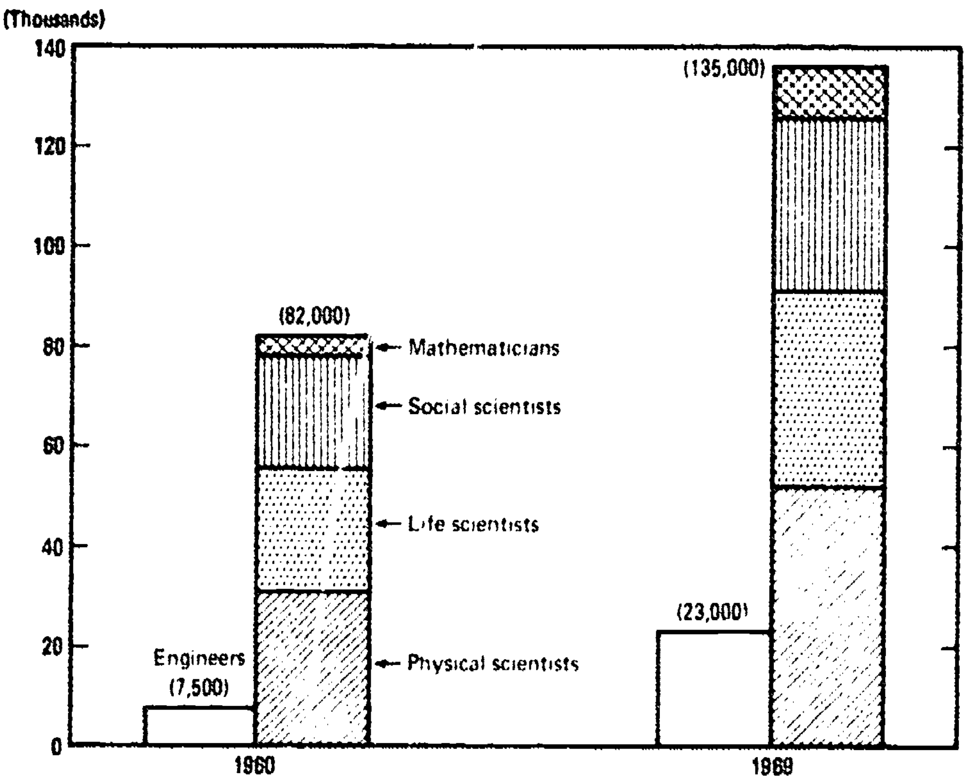
*Information on the current numbers, types of employer, employment activities, etc., of scientists must be assembled from numerous data sources. Since not all of these are updated annually, it is only possible to develop the latest complete picture for 1969, even though many pieces of this mosaic are already available for 1971.

†Since these data refer to primary activity, most academic personnel are included in the non-R&D group.

Chart 5. Total scientists and engineers, 1960 and 1969.

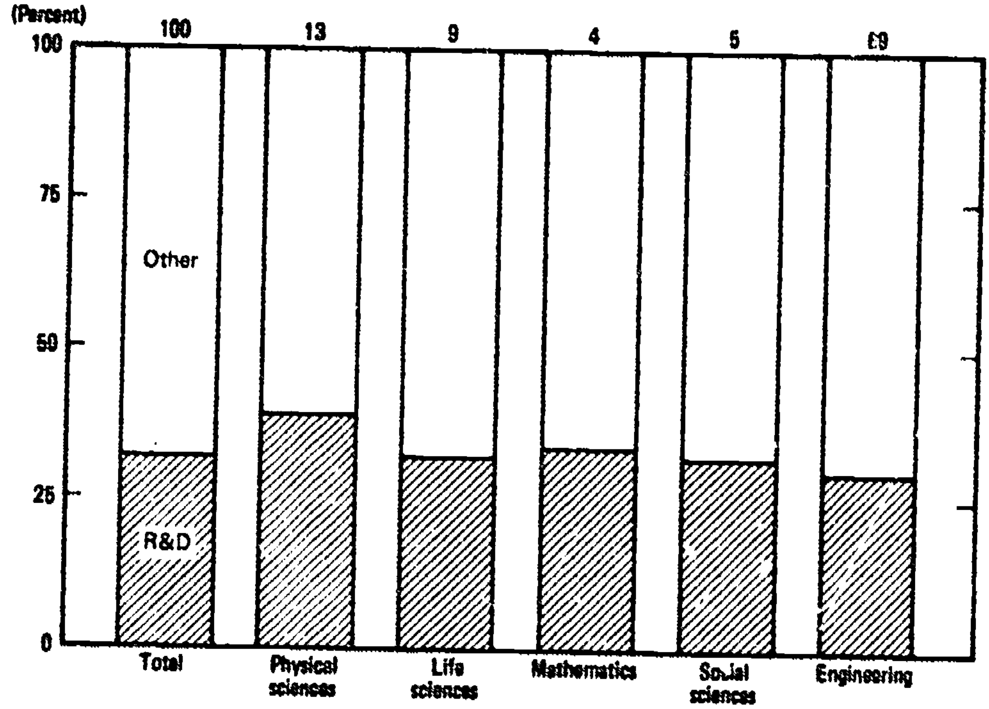


Ph.D. scientists and engineers, 1960 and 1969.

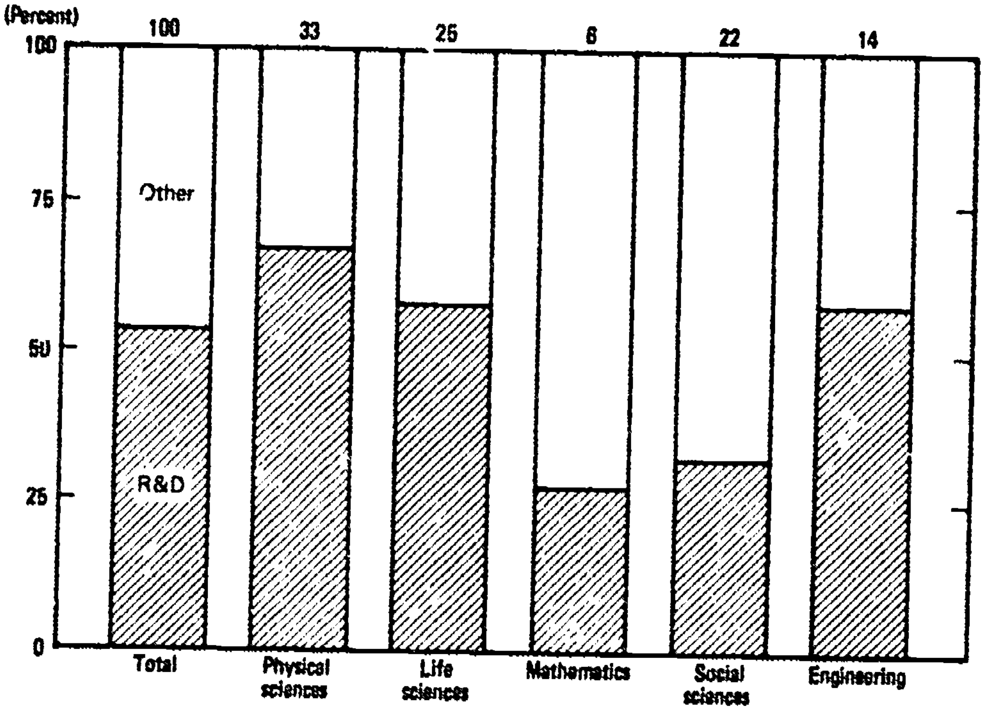


SOURCE: Bureau of Labor Statistics and National Science Foundation.

Chart 6. Distribution of non-Ph.D. scientists and engineers, by activity and area, 1969.



Distribution of Ph.D. scientists and engineers, by activity and area, 1969.



SOURCE: Bureau of Labor Statistics and National Science Foundation.

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dents who intend to work towards careers as research scientists has decreased steadily from 3.5 percent in 1966 to 2.5 percent in 1971, while similar data for interest in engineering careers show a decrease from 9 percent to 5.3 percent. While these relative changes of career interest are small from a statistical point of view, they do appear to be significant because the data show a steady trend and thus seem to be indicative of a decrease in interest in science and engineering careers among college freshmen. During the same time interval, the total number of freshmen increased by about 37 percent.[4] Thus, if these students actually follow their plans, the absolute number of new entries into these occupations would remain approximately constant. It should, of course, be realized that freshmen frequently change career objectives during the course of their college education. However, this is not as prevalent among those opting for science and engineering as among the rest of the student body.[8] A more definitive indication of change in interest can be observed from the data collected by the Office of Education[9] and the National Science Foundation[10] on graduate enrollments. As shown by chart 7, since 1964 there has been a relative decrease in graduate science studies, primarily in the physical sciences and engineering. Furthermore, NSF data collected from 212 doctorate-granting institutions show between fall 1969 and 1971 an absolute 7.2 percent decrease in first-year full-time graduate enrollments in science (table 1). Such a decrease is not reflected in OE[9] data which covers all institutions providing graduate training.

Table 1–Changes in first-year, full-time enrollment in doctorate science departments in U.S. universities, 1970-71

	All institutions	*20 top universities*[a]	*127 intermediate universities*[b]	*65 developing graduate schools*[c]
First-year, full-time enrollment . . .	39,940	10,184	25,479	4,277
1969-70 change	2.2%	-7.4%	-0.2%	+0.1%
1970-71 change	5.0%	-7.8%	-4.2%	-3.0%

[a]The top 20 Graduate Institutions–selected on the basis of the number of NSF fellows who chose a particular institution for graduate study and the amount of Federal R&D money awarded to the institution.

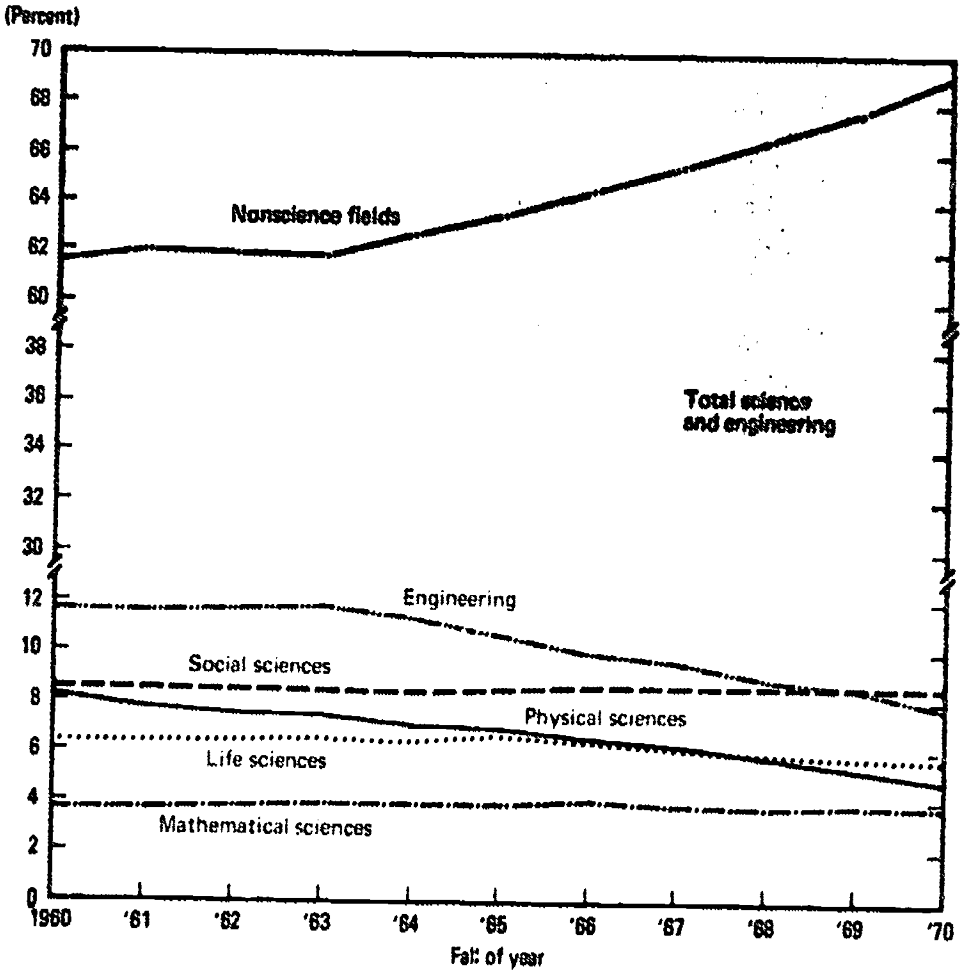
[b]127 remaining institutions called "Intermediate."

[c]65 Developing Graduate Institutions–those awarding science Ph.D.'s in 1960 and afterwards.

Source: National Science Foundation.

The observed relative and possibly absolute decreases in science enrollments ar due to a number of factors. Students have become much more sensitive to some of the mal-effects which sometimes are the byproducts of technology, while frequently not completely aware of the many beneficial aspects. This sensitivity, coupled with increased interest in social problems, has undoubtedly influenced student career choices away from the natural sciences and has been at least partially responsible for the relatively large increases in social science baccalaureates and the growing interest in careers in law and medicine.[1 2] Feedback of actual and exaggerated information of changes in employment opportunities and the prospect of reduced Federal financial support

Chart 7. Total enrollment for advanced degrees, science and engineering as a percent of all fields, fall 1960 to fall 1970.



SOURCE: Office of Education.

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have also undoubtedly contributed to the veering-away from science on the part of students.

The situation is aggravated beyond quantitative considerations because recent decreases in enrollment appear initially to have been much more severe in the top institutions (table 1). It should be noted that some of the reductions in size of the first-year graduate school classes are self-imposed by the institutions. The reasons for this seem to be diverse, varying from the belief that student-to-faculty ratios have become too large to financial considerations based on the high cost of graduate education. One frequently mentioned reason is that departments do not want to accept graduate students unless they are able to provide them with financial support during the course of their graduate training. Thus, recent reductions in Federal academic science funding (chart 1), as reflected in the more limited availability of research assistantships, fellowships, and traineeships, have undoubtedly been one of the factors responsible for this self-imposed limitation.

Under- and Unemployment

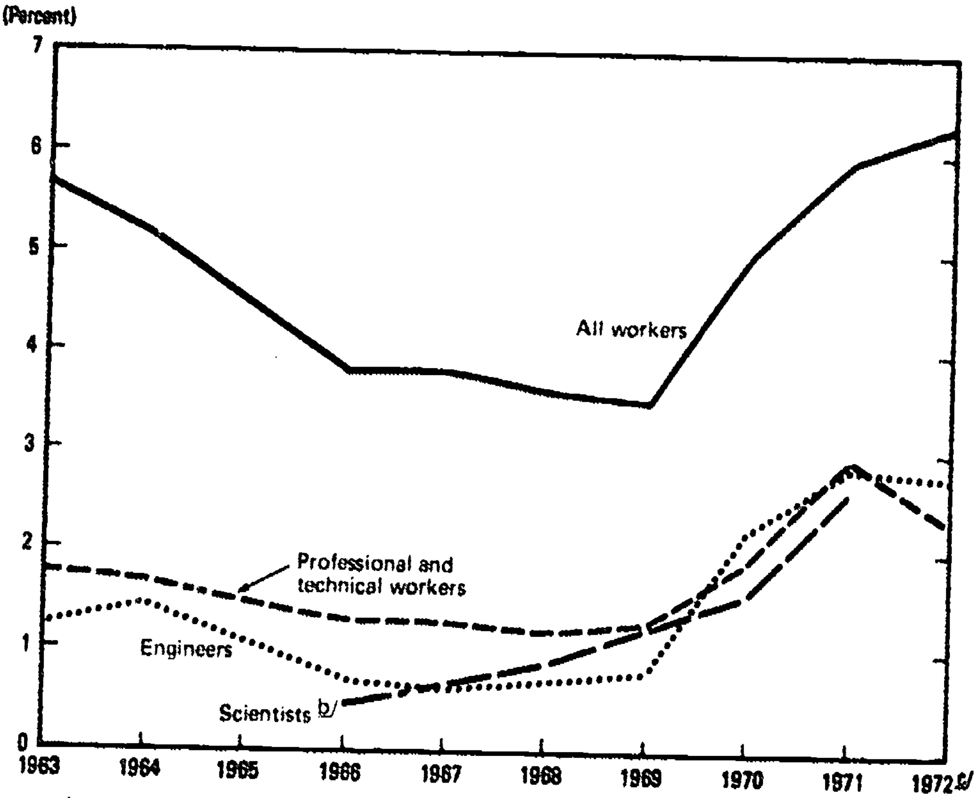
The situation of the last three to four years reflects a significant change in both the potential supply and the actual utilization of scientists and engineers with unemployment and underemployment becoming an increasingly important and worrisome issue. It is clear that these problems are the result of the convergence of a number of different factors.

In terms of current dollars, national R&D expenditures have increased continuously. However, between 1967 and 1971 the level of total R&D funding in terms of 1967 dollars has declined on the average by 1.5 percent per year.[13] This decrease in R&D expenditures has been due primarily to an average annual decrease of 4 percent in Federal R&D funding which is, however, increasing by 5 percent in FY 1972 and expected to grow further by 4 percent in 1973. Non-Federal R&D expenditures have continued to increase by an average of 2.2 percent per year[13] though this rate has been declining in the last two years. The latest McGraw-Hill Survey[14] predicts continued growth of business R&D funding until 1974 at an annual rate of 6 percent in terms of current dollars. However, anecdotal evidence raises the question as to whether a leveling-off in non-Federal R&D funding might not be experienced now as a result of the past sluggishness of the economy. Aca-

demic science funding from non-Federal sources has also been under severe pressure as a result of the financial burdens of State Governments and the general state of the economy which has reduced private donations. At the same time, there has been a fairly steady period of inflation, which for research expenditures is even more severe than that indicated by the changes in the GNP Implicit Price Deflator. For example, an academic R&D price index developed by NSF shows an increase of 32 percent over the last six years[15] as compared to a 26-percent increase in the GNP Deflator.

As a result of these various phenomena, since 1969 unemployment of scientists and engineers has accelerated—the employment rate during 1971 being 2.6 percent for scientists and 2.9 percent for engineers (chart 8). Best current estimates of unemployed scientists and engineers

Chart 8. Unemployment rates a/ for all workers, professional and technical workers, scientists, and engineers, 1963-72.



a/ Annual data not seasonally adjusted.
b/ Data are for spring of year.
c/ Data are for the first quarter only.
SOURCE: Bureau of Labor Statistics.

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are of the order of 50,000 to 65,000. While the estimate of this total number is fairly good, relatively little has been known about details of the situation such as the age distribution of the unemployed, the length of the period of unemployment, the geographical distribution of unemployed, the distribution among various fields of science and engineering, etc. Partial information has been available such as that on physicists, collected and analyzed by Grodzins,[16] data pertaining to chemists, collected by the American Chemical Society,[17] and statistics regarding 1971 Ph.D.'s and postdoctorals developed by the National Research Council.[20] However, in summer 1971, the National Science Foundation completed a survey of the 310,000 scientists[18] who responded to the 1970 National Register of Scientific and Technical Personnel and, in conjunction with the Engineers Joint Council, surveyed a sample of 100,000 engineers[19] picked from the membership lists of the professional societies that are a part of the Engineers Joint Council, the IEEE, and the American Institute of Aeronautics and Astronautics.

The scientists survey shows that 2.6 percent of the respondents were unemployed with 1.4-percent unemployment reported by doctorates. Scientists under 30 years of age showed by far the highest unemployment rate (5.3 percent), of any age group. Defense and space-related activities were cited as the last areas of employment by 11 percent and 4 percent of the unemployed. The average length of unemployment experienced as of June 1, 1971 was over seven months with about 45 percent of unemployed respondents reporting that their last science-related employment was supported to some degree by U.S. Government funds. While a total of 5.6 percent of the employed scientists were engaged in nonscience activities, only 1.6 percent of the total had accepted such positions since March 1970.

The situation for engineers was somewhat similar to that of scientists. Thus, 3.0 percent reported to be unemployed and seeking employment in the June-July 1971 period, with doctorates showing a smaller unemployment rate of 1.9 percent. Again, the younger engineers showed the greatest unemployment rate--5.5 percent for those under 24 years. However, in contrast to the scientists, engineering unemployment did not decrease uniformly as a function of age, but showed an upturn for the oldest group—55 to 64 years. As expected, the unemployment rate for engineers previously involved in space and defense activities was higher than the average, i.e., 6.3 percent and 4.8 percent, respectively. Furthermore, engineers who were not directly supported

by Federal funds reported a lower than average 2.3-percent unemployment rate.

To many, the unemployment numbers stated here might appear small compared to other figures quoted in the press, in speeches, or in interviews. However, the larger figures are frequently the product of inadvertent misinterpretations of information. For example, data have been collected on the unemployment of scientists, engineers and technicians as a group; yet, this number is frequently quoted as being the unemployment rate for only scientists and engineers. Surveys have also been made of the numbers of scientists who were laid off by a particular industry; for example, the aerospace industry. Frequently, such numbers are then quoted to represent the number of unemployed scientists; yet, some of the same surveys show that a major fraction of those laid off were employed again within a period of months. Another common mistake is that of grouping unemployed scientists with those reported as temporarily employed, an example being the comments by Sutter in a recent report of the American Chemical Society.[17] Such combination of two completely different groups is inappropriate since the temporarily-employed scientist is legitimately employed, frequently with full utilization of his training. Another erroneous approach is to generalize on the basis of the unemployment situation in a particular geographic area or field of science. For example, it is clear that physicists seem to be especially hard hit and that the situation in certain U.S. cities such as Los Angeles, Seattle, Boston, etc., is much worse than indicated by the national mean. Serious as these regional and field avariations are, they are not representative of the overall national picture.

In summary, there has been a very significant relative increase in the unemployment rate for scientists and engineers. On the other hand, it must be remembered that the starting point for this comparison was a very low unemployment rate of less than 1 percent and that even with the recent large relative increases, the overall rate is still only about one-half as large as that for all workers in the labor force. Nevertheless, the current technical unemployment represents both personal and national problems. The personal hardships need no description except to point out that they involve individuals who have achieved considerable advanced training, frequently at personal sacrifice. From a national point of view, scientists and engineers represent an important resource which we cannot afford to lose on a permanent basis—a very real possibility if unemployed scientists move into other occupations.

The question of how to deal with this important problem is a most difficult one. One effective temporary mechanism affecting mostly younger scientists has been the Presidential Internship Program which provides one-year jobs at Federal Laboratories. Retraining is another possibility for scientists of all age groups. But, it is clear that it must provide more than a temporary solution. Unless we have a better notion of specific future demands, such an approach will only postpone our current problems with the result that when they reappear, the scientists affected will have their new hopes shattered with no one being better off. Thus, retraining for specific types of jobs, with the help of government and private support, will be most effective if essentially guaranteed jobs are available at the end of the training program. The only other type of retraining which may be helpful involves a diversification of knowledge and experience, which will make the unemployed scientists more suitable candidates for a wider variety of jobs. However, by far the most desirable short-range solution to the unemployment problems of scientists is an increase in job openings developed through the regular demand mechanisms of economic and government programmatic needs.

With unemployment still being relatively small, there is the matter of underemployment, i.e., employment that does not utilize the training of a scientist. While being a very real issue, it is one for which it is most difficult to obtain unambiguous data. The determination of underutilization of training involves very subjective judgments. Clearly, the Ph.D. in chemistry who is forced to drive a taxi is underemployed. But how about the high-energy physicist who is working in industrial optical design, the research engineer who is now in the technical sales department of a high technology industry, or the Ph.D. biologist teaching in a four-year college? The individuals involved might consider themselves underemployed, but would others share this judgment? Some indication of the magnitude of underemployment of new Ph.D.'s has been provided by a departmental chairman survey[20] carried out by the National Academy of Sciences. Using the following definition,

> "Appropriate work is interpreted to include a faculty or research staff appointment in any university, college, or junior college, a research or research administration position in industry, government, or elsewhere, or any professional positions which was the deliberate choice of the graduate."

this survey found that in January 1971, 1.2 percent of new Ph.D.'s

were listed as being employed in positions that do not appropriately use their graduate training.

Two aspects seem to emerge from the experience of the last few years. Regardless of the magnitude of actual unemployment, we have a considerable number of scientists who are not very content in their new jobs and who have experienced serious dislocations. A real mismatch exists between aspirations and opportunities. Considering both short- and long-term prospects, it seems clear that aspirations must be broadened and that the value spectrum, i.e., professional value placed on different types of activities, must be extended. This is primarily a task for the academic and scientific community. The other dominant characteristic of recent changes in the employment picture has been the rapidity of the course of events. This has injected a degree of instability into the plans and activities of individual scientists and institutions that has made adjustments and orderly planning extremely difficult. While many of the events contributing to the recent problems are difficult to prevent or to correct rapidly, some probably could have been avoided by more careful advance analyses of the effects of specific actions.

THE FUTURE

In reviewing future scientific manpower supply/utilization analyses, one can group available forecasts into two broad general categories. One of them involves the most "immediate future," i.e., the next two to three years. This period is of greatest concern to those who are presently under- or unemployed as well as students and postdoctorates who expect to enter the labor market during this period. The other category is the "long-range" future, i.e., the next 10 to 20 years. This is of special importance to those concerned with the overall welfare of the national science and technology enterprise because decisions made today affecting the production of scientists will start bearing fruit only during the latter half of this decade. Thus, these decisions could be decisive in producing imbalances at a later time. Another group with a prime interest in the long-range outlook involves universities and colleges which have to plan for staff, facilities, and funds to accommodate the number of students likely to be enrolled during the next two decades. Finally, students who are just embarking on study programs leading to careers in science are vitally interested in the probable nature of the demand for their services 8 to 10 years from now.

The Immediate Future

The supply available during the next few years cannot change very much from expected levels, since graduates of that period are already in the academic pipeline. The only unexpected change affecting the immediate supply can come from marked changes in emigration/immigration patterns and variations in the number of graduates that will not even try to obtain science jobs. It is now impossible to obtain data on emigration since only a passport is required for that purpose. Also, no statistical data are collected on the occupation of the passport holders leaving the United States or on the purpose of their trips. However, considering the current prospects for employment, it seems likely that larger numbers of foreign scientists who came to the United States to work or study—as well as some U.S. scientists—will look for employment opportunities in other countries. Immigration amounted to about

13,000 scientists and engineers[21] in 1970-71, but is likely to decrease because of the recent removal of scientists and engineers from the Department of Labor's list of "shortage" occupations. This makes it much more difficult for foreign scientists to enter the United States to accept employment.

During the immediate future, we will be graduating about 250,000 baccalaureates, 70,000 master's and 18,000 Ph.D.'s in sciences and engineering per year. However, not all of these will enter the labor force. Although current followup data on graduates are not available, we do know on the basis of somewhat outdated followup studies[6] carried out in 1963 that only about 35 percent of baccalaureates entered the science and engineering work force directly. The rest went to graduate school, entered nonscience occupations, entered military service, left the country, or did not enter any work activity. How this fraction will be affected by the tightening job market is not clear. More recent information should be available within a year from studies being carried out for the NSF by the American Council on Education (ACE). On the other hand, recent data on Ph.D.'s[22] show that they generally do enter science careers. The lack of current information on post-graduate activities of science students makes it difficult to predict how many new graduates will be looking for science jobs in the next year or two. On the basis of the expected number of degrees and past post-graduate patterns one can venture a guess that those seeking science jobs will amount to 100,000 to 130,000 per year. It should be remembered that many will be needed to fill vacancies created by death, retirement, disablement, changes by presently employed scientists to nonscientific careers, etc. This is well illustrated by what actually happened in 1965 when there was relatively little unemployment. In that year, 145,000 degrees of all types were granted in the natural sciences and engineering; yet, the total number of employed natural scientists and engineers increased by only 41,000.

Clearly, two principal variables will affect employment opportunities for scientists over the next two-to-three-year period. The first of these is the status of the national economy, which will directly affect the level of industrial activity in high-technology industries. While the outlook is optimistic at this time, it is difficult to predict in detail what is likely to happen over the next 25 months. The other variable is the amount of Federal funds available for the purchases of goods and services, for the support of research and development, and for academic

science. The last two items are especially important in determining the market for doctorates since these are predominantly engaged in research and development or employed in academic institutions. While academic enrollments are expected to continue to increase, no relief to ameliorate the financial pressures on universities and colleges is in sight. Many universities are in the process of retrenchment and under present circumstances, no increased demand for doctorates should be expected from the higher education sector.

The Fiscal Year 1972 Federal Budget and the FY 1973 Budget presented by the President to the Congress involve significant increases of 8.6 percent and 8.5 percent, respectively, for R&D obligations, including 11.6 percent annual increases for research and development conducted in universities.[23] However, it must be realized that these funds are generally not available for obligation by the Federal agencies until the midpoint of the fiscal year and that their subsequent obligations to individual institutions will take place during the last half of the fiscal year. Thus, the effect of these increased FY 1972-73 R&D funds on the employment of additional scientists and engineers will in all likelihood not be felt to any significant extent until the second half of 1972 or later. This fact is reflected in the *Special Analyses of the Budget of the U.S. Government* (tables R-1 and R-3), which show that FY 1972 expenditure estimates for the conduct of research and development are expected to increase by 5.2 percent and those for FY 1973 by 4.4 percent. In considering these increases, it must be kept in mind that they are in terms of current dollars and that any inflationary effects will correspondingly reduce their actual effectiveness in providing new employment opportunities.

The Long-Range Future

Studies of possible future supply/demand situations depend mainly upon analyses of past trends and of changes in trends and assumptions about likely magnitudes of future key parameters. Thus, these analyses are essentially projections. These are made with more confidence, though not necessarily more accuracy, when relatively steady long-term trends have been in existence and when there is no evidence of likely changes during the period under review. This is clearly not the situation at the present time when, as shown in previous parts of this paper, we are in the midst of a period of rapid transition

with past trends already showing indications of marked change. Before discussing some of the projections which have been made in recent times, a word of caution is in order. Projections definitely should not be considered as predictions; they can only show what future situations might be like under certain assumptions and with no significant breaks in trends. One of their most useful purposes is to provide an understanding of the nature of key parameters and how they will affect future relationships. As such, they provide the policymaker with options for actions to affect both the supply and demand side of the equation.

A number of supply/utilization projections have been published within the last year dealing with: scientists and engineers as a total group, such as those produced by the Bureau of Labor Statistics (BLS);[24] the doctorate part of the scientists population, such as those made by NSF;[25] Froomkin;[26] and Cartter;[27] or subgroups of specific disciplines such as the ones produced by Brode[28] and Gruner.[29] In addition, the Office of Education (O.E.),[30] Hall,[31] and McGinnis[32] have made projections of science baccalaureate and/or doctorate production which affect the supply aspects of the issue. The periods covered by the projections vary, with the NSF and BLS projections covering the period ending by 1980, while Cartter proceeds as far as 1985, and Brode tries to see as far into the future as the year 2000.

Certain key parameters are almost always taken into consideration in all of these projections. In considering future supply, the studies consider: attrition due to death and retirement; the number of scientists and engineers produced by universities and colleges; retention of new graduates within the science and engineering labor force; emigration from and immigration into the United States; and mobility into science activities from nonscience areas. The demand aspect of the problem is generally analyzed along major sectors of either employer or activity. The academic sector is usually treated as a single entity with such considerations as: future enrollments; student to-faculty ratios; the ratio of Ph.D.'s to non-Ph.D.'s among newly acquired faculty; and differences between these parameters among various subcomponents of academia such as two-year colleges, four-year colleges, and graduate schools. Another group is made up of those scientists involved in nonacademic R&D activities, principally in industry and government. Key parameters for the nonacademic R&D sector are magnitude of R&D funds likely to be available, the increase in R&D cost per scientist, and

the ratio of Ph.D.'s to non-Ph.D.'s likely to be hired by nonacademic employers for R&D activities. A third or "other" group is comprised of those scientists and engineers that use their scientific background in their work, but are neither engaged in research and development or academic activities. The latter sector includes those who are in management or administration; consulting; non-R&D industrial activities such as production, marketing, technical sales, etc.; and those who are practitioners of science, using their scientific skill in dealing with such problems as quality control in industrial plants, social work, ecological monitoring, weather forecasting, etc. Especially among the projections of Ph.D. utilization, this last group is frequently not considered adequately, even though the NSF National Register of Scientific and Technical Personnel has shown that the number of doctorates engaged in these types of "other activities" has increased from 4 percent to 10 percent during the '60's—a period primarily characterized by a shortage of Ph.D.'s.

Supply

The Bureau of Labor Statistics has estimated the total number of college educated workers entering the labor force between 1968-80 at 10.5 million, but does not break this figure down by broad professional groups such as scientists and engineers. Its most recent report[24] does cover particular professions such as life scientists and chemists, but specific numbers of available scientists are not presented. Instead, the analysis considers rates of production as predicted by O.E. and entry from other sources such as the Armed Forces or other fields, etc.

Only three analyses—NSF,[25] Froomkin,[26] and Cartter[27]—take into consideration the various factors mentioned previously, and project future numbers of active doctorate scientists and engineers (table 2). All these supply figures lie within a 10-percent range, which can be considered in fairly good agreement considering the inherent uncertainties in this type of projection.

The key factor in the projection of future supply is the number of new scientists and engineers produced. Here, as illustrated by doctorate forecasts in table 3, there is no clear consensus among projectors, though a cluster of almost identical forecasts emerges. Some of the variations can be explained by differences in methodology. Thus, the O.E. and Hall projections are based essentially on a continuation of

Table 2–Supply and utilization projections for doctorate scientists and engineers, 1980

(in thousands)

	Supply		Utilization		Difference
	Range	*Average*	*Range*	*Average*	*of averages*
Cartter	321-343[a]	332	285-315[b]	300	–32
NSF	316-336	326	270-298	284	–42
Froomkin	305		N.A.		

[a]Adjusted for the 1970-80 period from 350,000-400,000 Ph.D. production figure quoted in Reference 27 for 1970-85 period and subtracting 27,000 for net loss due to emigration/immigration and attrition of the group receiving degrees between 1970-80.

[b]Adjusted for the 1970-80 period from incremental academic and non-academic utilization figures quoted in Reference 27 for the 1970-85 period and added to 1970 base figure of NSF.

trends observed for the last ten years. On the other hand, the NSF and Cartter figures are based on computations that give disproportionate weight to trend data of more recent years when science baccalaureate production and graduate enrollments experienced decreasing growth rates. Thus, these latter projections come up with considerably smaller degree production numbers. The NSF model is a dynamic one which considers trends and relationships of ratios of first-year graduate students to baccalaureates, total graduate enrollment to first-year enrollments, and finally, Ph.D. production to graduate enrollment. McGinnis[32] has tested and used the hypothesis that science-doctorate production is linearly related to Federal R&D obligations with a lag time of about five to six years. Using a cubic or a logarithmic function to project Federal R&D obligations, he calculates science-doctorate production during the seventies which agrees with the lower projections. Brode uses the assumption that only about 40 percent of the 22-year-old population is capable of being motivated to obtain a bachelor's degree in natural science and engineering. He projects for these areas of science a saturation Ph.D. production rate of 0.7 percent of 28-year-olds and arrives at a 1980 annual natural sciences and engineering Ph.D. production figure of 26,000. This estimate compares with 30,000 extrapolated by Hall[31] and O.E.,[30] and a considerably lower figure of 18,000 derived by NSF.[25] Again, the differences between the higher and lower projections are due to methodological differences with the lower figures being based on recent changes in student interests in

science education as indicated by decreased growth rates in degree production and graduate enrollments. The lowest number, generated by NSF, is consistent with the cumulative 1969-80 doctorate production and active science doctorate figures of Cartter and Froomkin (tables 2 and 3).

Table 3–Cumulative science and engineering doctorate production projections, 1970-1980

NSF[25]	216,000-240,000
Cartter[27]	220,000-252,000
McGinnis[32]	223,000-226,000
Hall[31]	279,000
Office of Education[30a]	316,000

[a]Adjusted by NSF to exclude fields from "social sciences" not ordinarily classified as "social science" in the other projections, such as social work, public administration, etc.

Utilization

The Bureau of Labor Statistics[24] has made projections of the total number of scientists—including all levels of educational attainment—required in specific professions based on certain assumptions, as well as on interviews with prospective employers of scientists. The key assumptions are a 4.3 percent per year increase in real GNP, a full-employment situation (3- to 4-percent total unemployment) by 1980, and Armed Forces strength at essentially the pre-Vietnam level.

With respect to utilization of doctorates, detailed numerical calculations have been undertaken by Froomkin,[26] Cartter,[27] and NSF.[25] The NSF and Cartter utilization projections lie within a 5-percent range (table 2). Froomkin does not make independent projections of utilization, but indicates how his projected science doctorate pool would be utilized on the basis of either 1968 utilization patterns or his own projected utilization pattern, with the "slack" always being taken up by the "other" group. With respect to disciplines, the NSF study does make 1980 projections by broad areas of science while Cartter only covers faculty requirements for four specific fields for a number of years up to 1985.

Again, different methodologies and assumptions are employed in the various analyses. In the case of the doctorate group, Cartter covers primarily academic utilization requirements and makes some rather

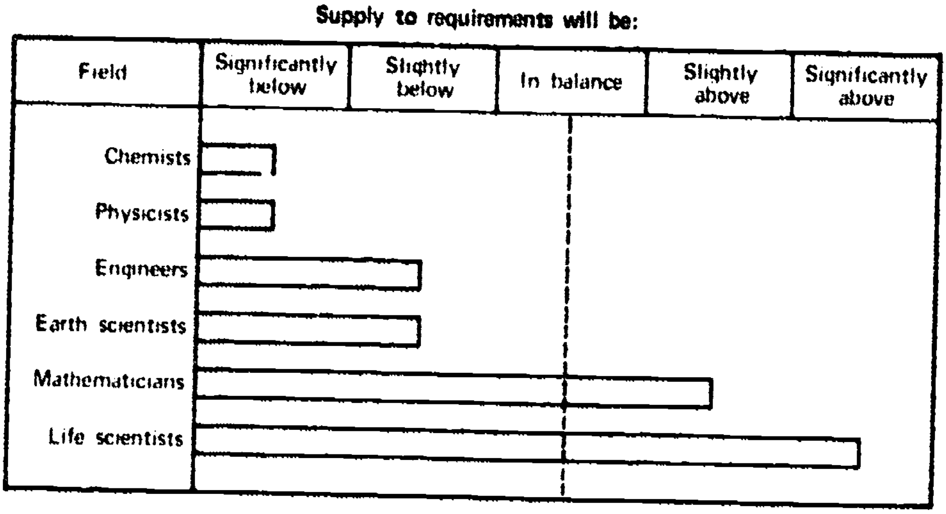
general assumptions about the nature of nonacademic needs while assuming either maintenance of present quality standards in academic faculty (same proportion of Ph.D.'s) or improvement of teaching quality through improvement of the Ph.D.-to-total-faculty ratios. NSF covers the three groups—academic, nonacademic research and development, and "other"—in considerable detail making specific assumptions about ranges of such factors as: 1980 R&D funds as percent of GNP (2.7 percent to 3.0 percent); growth rate of real GNP (4.3 percent/year between 1968-80); increases in the proportion of doctorates to be hired between now and 1980, with the increases in academia being larger than those in the nonacademic sectors; and growth of the proportion of total doctorates active in "other" activities. The NSF study is the only one which a'so calculates and lists the sensitivity of its projections to each of the explicitly stated assumptions.

Differences Between Demand and Supply

For the period up to 1980, chart 9 summarizes the situation for those scientific professions covered by the BLS analysis. As can be noted, significant shortages are projected for chemists and physicists, and potential major oversupplies for mathematicians and life scientists. It should be remembered that this analysis covers baccalaureates, master's, and doctorates as a single group and is based on relatively optimistic assumptions.

With respect to the doctorate situation, table 2 shows that by 1980 both Cartter and NSF project an average potential oversupply of about 10 percent to 13 percent. As seen from chart 10 the NSF analysis projects the greatest problem for engineering doctorates, who have been increasing at an annual rate of more than 15 percent and for social scientists of whom about 75 percent are now in universities and colleges. The physical scientists appear to be likely to have the least problems because the majority—60 percent—are employed in nonacademic sectors and also because of the fact that their baccalaureate production has remained essentially constant in recent years (chart 4). NSF, Cartter, and Froomkin all indicate that there is a great likelihood that a significant number of future doctorates will be engaged in activities markedly different from those of the majority of the present group. Thus, NSF projects that slightly more than one-half of the doctorates produced between 1969 and 1980 will be teaching in two- and four-

Chart 9. Relation of supply to requirements in science and engineering, 1980.

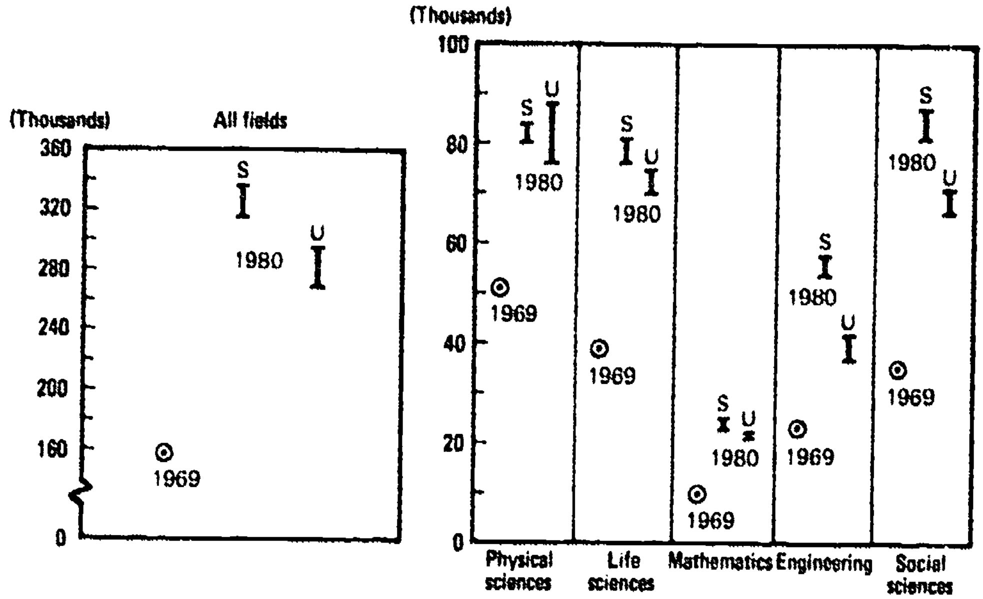


SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, College Educated Workers, 1968-80.

year colleges or will be engaged in nonacademic, non-R&D work, while Cartter warns that "an increasing proportion of these specialists will not be employed in jobs for which they were trained or to which they aspire." A good critique of recent doctorate supply/utilization projections has been made by Wolfle and Kidd.[33]

The picture for the next decade—in spite of projected imbalances—is still one in which an equilibrium between demand and supply may be achieved. This especially may be the case if the recently observed decreases in student interests in careers in science continue or even accelerate. Only time will tell. However, grave concern, though in opposing directions, has been expressed about the situation in the eighties because of demographic aspects. The birth rate in the United States declined starting in 1960, with the result that the number of 18-year-olds will start to decline in 1979. Many believe that this will produce related decreases in baccalaureates starting in 1982, graduate enrollments starting in the early eighties, and doctorates starting in 1986. Whether these decreases will actually be observed depends on whether the increasing trends towards high school graduation, as well as college and graduate education, will continue. Many, such as Cartter, feel that even with a continuation of these trends, by 1980 we will have

Chart 10. Supply and utilization of science and engineering doctorates, by broad area of science, 1969 and 1980.



NOTE Vertical bars indicate range between high and low projected values of supply and utilization.
SOURCE National Science Foundation.

reached a stage of saturation, at least with respect to the percentage of the appropriate age groups receiving baccalaureate or advanced degrees. Brode, with his assumption of only a constant percentage of the age group being capable or motivated to go into science, predicts a reduction in the number of science graduates and enrollments. If this turns out to be the case, it will have at least two impacts on the demand/supply relationship in that academic faculty requirements as well as the supply of new doctorates will decrease. The former will especially affect those areas—such as mathematics, and social sciences and life sciences—where doctorates are now predominantly employed by universities and colleges. This has led Cartter to conclude that in the eighties we may be producing one-third too many science Ph.D.'s "for the type of employment we have known in the past" and to suggest that future enrollment goals be carefully reassessed, an admonition which is also given by the NSF even for more short-term consideration. On the other hand, Brode feels that a continuation of the birth rate decline will produce such a serious cumulative shortage of scientists in the eighties and nineties that he urges that enrollments be maintained and steps be

taken to preserve the possible excess which could be produced during the seventies.

It would appear that we should not further discourage students from entering careers in science, since feedback effects due to the somewhat exaggerated accounts of the present situation seem already to have affected future scientist production. Thus, if the 1970 graduate enrollment decrease represents the beginning of a trend, we might be well on the way to produce a renewed shortage of scientists by the late seventies. On the other hand, it seems imperative that students be counseled at the time they make a decision to enter science careers on the probabilities of being able to carry out specific activities such as research and the opportunities and challenges in nonresearch activities. This explanation of options must be accompanied by convincing assurances of the societal and self-satisfying values of other types of scientific activities. Having counseled students to be ready to engage in a variety of scientific activities, universities and colleges must then be prepared to offer young people broader and more diverse training programs with more curriculum and probably more degree options to provide the best training for the projected large number of students who will enter neither university nor R&D careers. These programs should be responsive to the needs of students to obtain direct experience with various types of technical work. New approaches could include work-study programs or internships to give students direct experience with various types of science activities and different types of employers.

A word of caution is in order for those who feel that our many social needs with technological components will clearly require the services of all the scientists we are able to produce. This assessment is undoubtedly correct, yet the utilization of scientists does not depend solely upon needs, which are virtually unlimited, but rather upon the resources which society is likely to make available to deal with these needs. Such resource allocation decisions are influenced by numerous political, social and other factors and, as must be evident from the present situation, the available resources will always be limited. Estimates of the likely magnitude of these future resources produce the utilization limitations described above. On the other hand, it must also be realized that with a finite, though as yet undetermined, fraction of the population capable of becoming scientists, manpower production constraints do place an upper limit on the quantity of resources that could be utilized. A continuing evaluation of this last aspect, taking

into consideration the changing characteristics of college students and their motivations, seems very much in order.

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