Chapter 1

The projections and planning of engineering, the physical sciences, the social sciences, and the biological sciences manpower naturally breaks up into four main categories. Engineering was discussed by Mr. John Alden, Executive Secretary, Engineering Manpower Commission; the physical sciences by Dr. William C. Kelly, Director, Office of Scientific Personnel, National Research Council; the social sciences by Dr. Elbridge Sibley, Executive Associate, Social Sciences Research Council; and the biological sciences by Dr. Herbert Pahl, Acting Associate Director for Planning and Evaluation, National Institute of General Medical Science. In addition to these four general categories, Dr. Robert Alberty, Dean of the School of Sciences, discussed the two specialties, chemistry and physics.

Mr. Alden points out that doctorate engineers are still a small fraction of the general engineering manpower picture. Only recently has the large increase in Ph.D. production of engineers become significant. At the present time very poor statistics are available. Mr. Alden has done an excellent job of appraising the current trends in engineering and the need for Ph.D. engineers.

JOHN D. ALDEN: In attempting to assess the utilization patterns for advanced degree engineers and to make reasonable projections of future demand for people with skills traditionally associated with advanced degrees, we are faced with a general lack of firm statistics dealing with the present, let alone the future. It is obviously dangerous to draw too many conclusions from too few facts. What I have to say about advanced degree engineers must be viewed as a more or less subjective interpretation of such scanty statistics as I have been able to find plus those straws in the wind I have observed.

Manpower Projections

Graduate degree engineers, particularly those with doctorates, are still a rather small factor in the overall manpower picture, both for engineers and for doctorates in general. This perhaps accounts for the poor statistics available on them. Of the entire Ph.D. population of scientists and engineers described in two recent studies, engineers constitute 14% of one[1] and only 5% of the other.[2]

In the engineering profession, Ph.D.'s are an even smaller part of the total, ranging from only 1% in the postcensal study[3] to 5% in the most recent National Engineers Register profile.[4] The profession is being gradually enriched by a growing infusion of new advanced degree graduates, but even in 1969 only 6% of the engineering degrees awarded were doctorates.[5] The complete breakdown by degree level from the studies cited is as follows:

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1. National Science Foundation, "Science and Engineering Doctorate Supply and Utilization 1968-1980," NSF 69-37, U.S. Government Printing Office, Washington, D.C., November 1969.

2. National Academy of Sciences — National Research Council, "Profiles of Ph.D.'s in the Sciences," Publication 1293, Washington, D.C., 1965.

3. U.S. Bureau of the Census, "Characteristics of America's Engineers and Scientists: 1960 and 1962," Technical Paper 21, U.S. Government Printing Office, Washington, D.C., 1969.

4. Engineers Joint Council, "The Engineering Profession: A New Profile," New York, N.Y., 1969.

5. Engineering Manpower Commission of Engineers Joint Council, "Engineering and Technology Degrees 1968-69," reprinted from Engineering Education, 60, No. 5, January 1970.

Percent Distribution of Engineers by Degree Level

	No Degree	B.S.	M.S.	Ph.D.
Postcensal	45	45	8	1
National Engineers Register	3	70	22	5
1969 Degree Report	-	69	26	6

The rate at which the percentages are likely to change can be visualized by comparing the annual input of new engineering graduates (about 40,000) with the present total national employment of engineers (about 1,100,000).

In total numbers, then, we are dealing with about 20,100 Ph.D. engineers existing in 1968[6] who have since been joined by about 3,350 new graduates.[7] Published reports give varying figures on their areas of employment but are in general agreement that by far the majority are engaged in research or teaching. According to the NSF study,[8] 45% are employed in private industry, 45% in colleges and universities, 5% in government, and 4% elsewhere. Those employed in industry are primarily associated with research functions.[9] A survey conducted by the American Society for Engineering Education[10] found about 12% of the engineering Ph.D.'s in management. This study also disclosed that about half of those employed in private industry were engaged principally on government contracts, a proportion substantially greater than in the lower degree levels. The importance of this particular finding will become apparent in

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6. National Science Foundation, op. cit., p. 10.

7. Engineering Manpower Commission, op. cit., p. 2.

8. National Science Foundation, op. cit., p. 10.

9. Engineering Manpower Commission of Engineers Joint Council, "Demand for Engineers and Technicians — 1968," New York, N.Y., December 1969.

10. E. A. Walker et al., "Goals of Engineering Education — The Preliminary Report," American Society for Engineering Education, Washington, D.C., p. 39, October 1965.

connection with estimates of present and future demand for engineers.

The statistical studies cited have produced but little information about the personal characteristics of Ph.D. engineers. In comparison with other engineers, they are more likely to have come from a well-educated professional or white-collar family.[11] In comparison with other Ph.D.'s, however, the opposite is true.[12] Geographically they seem to be more concentrated in the Middle Atlantic states. They are more apt to remain employed in the field of their degree than biological, medical, or social scientists.[13] In general, the Ph.D. engineer "type" appears to be intermediate between the engineering and doctorate groups, sharing some of the characteristics of both.

The problem of measuring the demand for engineers in toto is so perplexing, in view of existing statistics and methodology, that it is perhaps reckless even to talk about the demand for Ph.D. engineers. Past surveys of demand conducted by the Engineering Manpower Commission of the Engineers Joint Council have developed only rudimentary data, much of it relative or subjective in nature.

In the 1964 survey, responding employers reported the greatest difficulty in filling their previous year's hiring goals for new Ph.D. engineers — only 63% of the desired Ph.D.'s were obtained in contrast to 82% of the bachelor's and 92% of the master's.[14] This same survey disclosed a few

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11. U.S. Bureau of the Census, op. cit., p. 13.

12. Ibid. Also National Academy of Sciences, op. cit., p. 34-39.

13. Ibid., p. 51.

14. Engineering Manpower Commission of Engineers Joint Council, "Demand for Engineers, Physical Scientists, and Technicians — 1964," New York, N.Y., July 1964.

signs of softening in the Ph.D. job market in the form of reduced hiring goals for physical scientists and mathematicians at this degree level.

Two years later, the next EMC demand survey revealed a different picture. Respondents reported that engineers were generally more difficult to hire than in 1965, but that the least difficulty was encountered at the Ph.D. level.[15] Employers found it easier to hire new Ph.D.'s than even non-graduates to fill engineering jobs. Softness was evident in the research, metals, aerospace, and consulting groups, and in state governments. Demand for advanced degree engineers still exceeded the available supply, but the relative demand for the different degree levels had shifted markedly.

The 1968 survey showed a picture similar to 1966: i.e., one of an overall shortage of engineers. Companies fell short of their previous year's hiring goals at all degree levels, yet hoped to hire more in the 1968-69 school year.[16] Relatively, the demand for Ph.D. engineers was again weaker than for most other educational levels as shown by the following indicators:

	B.S.	M.S.	Ph.D.
Shortfall in 1968 hiring goals	25%	22%	20%
Increase in planned hires for 1969	26%	28%	18%
Subjective index of hiring difficulty	100	66	47

What is the situation today? EMC has conducted a new survey of demand but the results have not yet been analyzed. Preliminary indications are that

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15. Engineering Manpower Commission of Engineers Joint Council, "Demand for Engineers and Technicians - 1966," New York, N.Y., November 1966.

16. Engineering Manpower Commission, "Demand for Engineers and Technicians - 1968," op. cit., p. 16.

hiring goals for 1970 are down markedly in the aerospace industry and to a lesser extent in the electrical-electronics, metal products, machinery, chemical, and R&D industrial groups and in educational institutions.[17] They are up in the construction and consulting, utilities, federal, state, and local government groups. Overall, planned hires are down only 1% from actual hires in 1969 but obviously the situation is quite unbalanced with respect to the different fields. In terms of total engineering employment, our figures show a slowdown in the growth rate to 2% or 3% per year for 1970 and 1971 in contrast with the 6-7% growth rates prevalent from 1964 to 1966. These estimates are not broken down by level of degree, so in looking ahead we can only make educated guesses on the future demand for advanced degree graduates.

Two recent studies have tried to gauge future needs and demand for this category of educated manpower. The NSF study mentioned earlier projected a supply of 350,000 Ph.D.'s by 1980 in contrast with demand estimates of 277,000 and 301,000 using two independent methods.[18] The lower of these estimates assumed a "minimal" 4.4% annual growth rate in federal R&D expenditures from 1968 to 1980. This same study hopefully concluded that "improved" utilization levels of Ph.D.'s would forestall a manpower surplus because "improvements in the present situation are quite desirable from a national point of view."[19] I think recent events have cast doubt on both of these assumptions, at least for the period of 1968-1971.

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17. J. D. Alden, "Some Preliminary Indications from the 1970 Engineering Manpower Commission Survey of the Demand for Engineers," Engineers Joint Council, New York, N.Y., April 1970.

18. National Science Foundation, op. cit., pp. 4-5.

19. Ibid., p. 3.

A second new study, by the Commission on Human Resources and Advanced Education, has reaffirmed the oft-stated conclusion that we are faced with an overall, long-term shortage of engineers. With regard to engineering doctorates, however, the study has little to say. Its authors make the assumption that a bachelor's degree graduate can increase his productivity 50 percent through doctorate study, but admit that "since there are no good measures of the comparative productivity of engineers at different levels of degree attainment, those percentages are hypothetical."[20]

The questions from the audience following Mr. Alden's talk concerned the possibility of increasing the mix of industrial employees with a Ph.D. to those without a Ph.D. degree.

QUESTION: There seems to be a paradox. The Ph.D. engineers are a very small fraction of the total engineering manpower supply. One would suppose that if a Ph.D. specialty began to grow rapidly the employers of engineers could use the supply by making very small fractional increase in the ratio of Ph.D. to non-Ph.D. engineers employed. This doesn't seem to be the practice in industry.

ALDEN: At what degree level industry hires engineers depends on what industry is looking to do and the particular job it has in mind. The salaries of the Ph.D.'s are substantially higher than the salaries of master's degree graduates and those in turn are substantially higher than for people with bachelor's degrees. I'm sure that the level of industrial jobs is not such that you would readily want to substitute Ph.D.'s for people at the

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20. John K. Folger, Helen S. Astin, and Alan E. Bayer, Human Resources and Higher Education, Staff Report of the Commission on Human Resources and Advanced Education, Russell Sage Foundation, New York, 1970, pp. 94-103.

bachelor's level which is where the bulk of the openings appear to be.

Job opportunities for the engineers with a bachelor's degree were discussed.

BRIAN SCHWARTZ: Could you briefly just discuss the B.S. degree engineer? What are his job prospects? Could you also comment on recent trends in the starting salaries for engineers, since salaries are a good indication of demand. In this very rapidly inflationary period the salaries of engineers have not been increasing rapidly. There have been very large layoffs of engineers and some salary cuts. For example, it was reported that at a division of North American Rockwell, 30 to 45% of the people working took a salary cut without a change in the work week. Though engineers are not unemployed, in constant dollar terms their salaries seem to be going down.

ALDEN: In my judgment job prospects for undergraduates are not as bad as they have been painted primarily because industries' demands are now basically in line with supply. I think that the draft is going to take a lot more bachelor's degree graduate engineers this year than it has ever taken before. My own analysis indicates that the draft will take somewhere between 8 and 12 thousand engineers off the labor market between the time of graduation in June and the end of 1970. If there were not a draft involved, we might have had a situation where the supply and demand would have become fairly imbalanced.

In past years the average engineering graduate at the B.S. level has probably had between 3 and 4 job offers. The apparently great decline in recruiting activity does not take into account the previous artificial situation where companies were not filling their quotas and students had many job offers.

Without the draft, the average graduate this year would perhaps have had between one and two job offers. He probably would not have been pounding the street. The escalation of draft calls on college graduates brought about by the lottery and some other extraneous factors is going to produce an artificial condition of scarcity at the bachelor's level because the total number of available B.S. degree graduates in engineering has been declining for the past 5 or 6 years.

Starting salaries offered to bachelor degree engineers were between 4 and 6% higher in dollar value this year than they had been the year before. There was no evidence in the wages or salary being offered that the companies felt that they had a surplus of engineers. I've heard nothing about salary cuts. Until we run the next salary survey in 1970 all we have are 1968 salary data. I really doubt that there have been that many salary cutbacks.

Dr. Kelly estimates 31,000 new physical science Ph.D.'s and a "demand" range, based on past employment data, of 23,200 to 46,400 new Ph.D.'s required.

WILLIAM C. KELLY: This report contains comments on manpower trends in the physical sciences and mathematics at the doctoral level. The four basic fields covered are physics, astronomy, chemistry, earth sciences (including atmospheric and space sciences), and mathematics (including pure and applied mathematics and computer sciences). We first present the available data from the recent past, then engage in a little speculation on what may lie immediately ahead, and conclude with comments about factors affecting these trends. The projections at the end apply to the short-term future, only to 1975. The longer term projections have been made in a study by the National

Science Foundation.[1] There are enough uncertainties in projecting to 1975 if the study is restricted to the major field level such as physical sciences compared with the total sciences and engineering. One should not try to extend these projections further.

The National Register of Scientific and Technical Personnel data for Ph.D.'s in the physical sciences and in mathematics for 1960-1968 give some notion of the size of the group. For the period of 1958 to 1962 perhaps 75% of the Ph.D.'s were included in the National Register. The number of Ph.D.'s in the National Register in the physical sciences and mathematics combined rose from about 35,000 in 1960 to 56,000 in 1968. This increase represents an average growth rate of about 7% per year. To convert the Register figures to the total physical sciences and mathematics population one can apply a factor of 4/3 to give 48,000 Ph.D.'s in 1960 and 76,000 in 1968 - as rough estimates.

The breakdown into the four major fields is as follows: The total number of Ph.D.'s in physics and astronomy — uncorrected for Register coverage — rose from 8,100 in 1960 to about 14,300 in 1968; in chemistry from about 19,500 to about 29,000; in the earth sciences from about 2,600 to 5,000, and in mathematics from 4,300 to 6,900. The distribution of Ph.D.'s in these fields by sector of employment shows that, with the exception of chemistry, these are academically based fields. Chemistry is different from the other three fields in that over half of the Ph.D. chemists are employed in industry rather than in academia. The reverse is true for physics, earth sciences,

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1. National Science Foundation, "Science and Engineering Doctorate Supply and Utilization 1968-1980," NSF 69-37, U.S. Government Printing Office, Washington, D.C., November 1969.

and mathematics.

The data on the number of doctoral degrees awarded annually by U.S. universities in the period 1960 to 1969 are on somewhat firmer ground than the total numbers of Ph.D.'s. The annual Ph.D. data are obtained from the Survey of Earned Doctorates conducted each year by the National Research Council[2] with the cooperation of the graduate deans and the Ph.D. recipients themselves. Individuals fill out a questionnaire before they receive the Ph.D. and return it to their graduate dean. The information is compiled in the Doctorate Records File. The coverage is about 99% of the students receiving earned degrees in the various scientific research fields. The statistics date back to about 1920.

The total number of doctorates awarded annually for the four combined fields in the physical sciences and mathematics rose from 2,100 in 1960 to 5,000 in 1969. The fraction of the Ph.D.'s among various fields has been remarkably constant over the last 15 years, with the exception of the growth of engineering Ph.D.'s. The growth rate for doctorates awarded annually in the physical sciences and mathematics has been about 9% a year for the period 1960 to 1968. The breakdown into numbers of Ph.D.'s awarded by field shows that Ph.D.'s earned in physics and astronomy rose from about 500 Ph.D.'s per year in 1960 to about 1,450 in 1969; in chemistry from 1,100 to 1,950; in earth sciences from 250 to 500; and in mathematics from 300 to 1,050. The awarding of physics doctorates almost tripled in that period, chemistry almost doubled, the earth sciences about doubled, and mathematics a little more than tripled. Though the year-by-year production of Ph.D.'s was not

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2. National Research Council, Office of Scientific Personnel, "Doctorate Recipients from United States Universities, Summary Reports for 1967, 1968, and 1969," Washington, D.C.

smooth, the average increase for mathematics and physics was a little more than 10% per year, while the earth sciences and chemistry showed a somewhat smaller percentage gain.

To project the future doctoral degrees awarded per year till 1975, data from a source other than the U.S. Office of Education have been used. The data came from a report made by Donald S. Bridgman[3] for the Commission on Human Resources and Advanced Education. The projection method used by Bridgman differed from that used in the projections by the U.S. Office of Education cited by other speakers in the Symposium. In forecasting the number of doctoral degrees to be awarded in a given year, the Office of Education used the total 17-18 year-old population nine years earlier as a base. Nine years was taken as the average interval from high school graduation to the attainment of the doctorate. Bridgman, in contrast, first determined the composition of the group receiving baccalaureates in a given year in each field by age, sex, and full-time or part-time status, and then projected the number of doctorates to be awarded after an interval that was specific to that field. The ratio of numbers of doctoral degrees to baccalaureates was used in the Bridgman projection instead of the ratio of the number of doctoral degrees to the 17-18 year-old population as used in the USOE projection. The Bridgman projections are about 15% higher on the average than those of the U.S. Office of Education. The annual number of Ph.D.'s graduated rises from about 5,800 in 1971 to 8,300 in 1975. The annual average rate of increase is about 8%, as contrasted with about 9% per year for the period 1960-1970.

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3. Donald S. Bridgman, Alternative Projections of Degree-Credit Enrollments and Earned Degrees in Higher Education, United States 1966-1975, Commission on Human Resources and Advanced Education, Washington, D.C., 1970.

Comparisons of supply and demand for the five-year period from 1971 to 1975 can be made. One first has to ask, "Supply of what and demand for what?" before one can understand what comparisons mean. It is, however, important to have some rough comparisons as guidelines. The data concerning the production of Ph.D.'s have been combined with some estimates about possible demands. According to the Bridgman projections, in the period of interest, 1971-1975, there will be about 35,000 Ph.D.'s granted in the physical sciences and mathematics. These projections have been corrected, somewhat arbitrarily, for the emigration of foreign doctorate recipients by including a 10% decrease (3,500). Only a 2% correction for attrition has been included, since new science Ph.D.'s are a rather young age group. Thus, the number of Ph.D.'s available for employment is about 31,000.

The demand projections have been made on two different bases. The first uses ratios obtained from the National Register of 1968 and estimates made by John Folger,[4] the Director of the Commission on Human Resources. The demand for faculty for this period, according to the Folger estimates, is about 11,600. In this period 7,400 Ph.D.'s will be needed for growth in enrollments, and about 4,200 will be needed for replacement. This employment pattern increases the ratio of the faculty in educational institutions with the Ph.D. degree from about 64%, which was the figure in 1962-63, to 75% in 1970, to over 90% in 1975. The Folger estimate assumed that the faculty-student ratio for full-time faculty people in four-year institutions, not including two-year colleges, would remain where it had been at about 1 to 18.

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4. John K. Folger, Helen S. Astin, and Alan E. Bayer, Human Resources and Higher Education, Staff Report of the Commission on Human Resources and Advanced Education, Russell Sage Foundation, New York, 1970.

The other part of the demand for Ph.D.'s covers the research jobs and other kinds of employment. In the 1968 Register there were about as many Ph.D.'s engaged in R&D activities in educational institutions as were engaged in teaching. Thus another 11,600 Ph.D.'s can be added to represent the R&D requirements of universities and colleges. According to the 1968 Register ratios, the demand elsewhere in industry and government for research and development people and other kinds of jobs is about equal to the total demand of the universities. Thus one must add another 23,200 to the demand to give a total demand of 46,400.

Another calculation can be made based on the assumption of what new Ph.D.'s have said they were planning to do in 1969. In the earlier part of this decade the number of newly graduating Ph.D.'s who indicated their intentions to do research was about twice that of those predominantly interested in teaching positions. In the 1969 survey of new Ph.D.'s, this ratio had changed to about half research and half teaching. These are intentions, of course, and do not actually represent accomplishments, but the predictive value of the statements is quite high. If one assumes that the faculty requirement is the same as that projected by Folger, 11,600, and adds in this new estimate of the requirement for research, a demand of 23,200 is obtained. We have two possibilities for demand: 46,400 in one projection, and 23,200 in the other. This must be compared with the reasonably firm figure for the available supply of about 31,000 Ph.D.'s. The two numbers for demand do not represent the bounds, but are two different kinds of estimates based on different assumptions.

Let us look more closely at the requirements for research personnel, according to various projections of demand. One has to consider the assumptions made about the support of research and the cost of doing research.

Both determine the demand for personnel in the R&D fields. Folger has made some estimates. Two possible assumptions for the percentage growth of R&D support and two possible assumptions on the cost of research were used to get a range for the demand. The research demand for doctorate personnel in all fields ranges between 19.9 thousand and 53.7 thousand. To break that demand down into the physical sciences and mathematics Ph.D.'s one can multiply by 0.47, which is the ratio of physical science and mathematics Ph.D.'s to the total. This gives a range of demand for these fields of 9,400 - 25,200 Ph.D.'s in R&D.

What is the employment situation of recent recipients of the Ph.D.? A survey was conducted by the National Research Council, early this year,[5] of their employment in all fields of the natural sciences, social sciences, engineering, and mathematics. The amount of outright unemployment reported in that survey was not large, but there was a great deal of unhappiness about the kind of jobs that people had to accept. There was considerable uncertainty about the situation for the 1970 Ph.D.'s.

The projections on manpower supply are based on the rate of awarding Ph.D.'s in the 1960's, when government funding of science was at a higher level than it is now. The present climate should reduce previous growth rates.

The audience questioned the projection technique used by the manpower experts. The need to constantly evaluate projections seemed apparent.

5. Office of Scientific Personnel, "Employment Status of Recent Recipients of the Doctorate," Science, 168, 930-939, May 22, 1970.

GRUNER: In physics and chemistry the number of bachelors being produced has stayed just about level. One would expect, therefore, only slight increases in Ph.D. production during the period indicated. Because of this, the Office of Education is reducing their earlier projection. Your prediction seems to indicate a supply which is considerably larger. How do you reconcile this?

KELLY: The Bridgman projections were based on many of the same assumptions as the USOE data. Both represent an upper limit. Personally, I would be inclined to scale them down. We should look at this situation in the light of present knowledge of trends. Certainly everything that I have seen indicates that it is not very likely that Ph.D.'s will be awarded at the rate that the estimated projections, based on historical trends, seem to indicate. If one were to put in the data for baccalaureate degrees in the recent past, one suspects that it would lead to a reduction in the number of expected Ph.D.'s.

GRUNER: In your second demand projection you only included education and research demand. What happened to the industrial demand?

KELLY: The industrial demand was included in the research requirements. This number does not really include the possibilities for new kinds of employment for Ph.D.'s. This point has been made in the NSF study and seems reasonable.

A comment made from the audience points to the difficulty of a manpower surplus for those students and employees currently caught in the rapidly changing marketplace.

COMMENT: If one goes back to 1960 and looks at the projections, then they underestimated the current supply situation. Presently you are saying the projections today are likely to overestimate the supply. This just shows that people are being rational in evaluating the market. Isn't the real problem today that some science and engineering student got caught in between an underestimated supply in 1960 and today's market? There really isn't a long-run problem, it is a short-run problem of adjusting to the transition. Something should be done about the people caught in between. I wouldn't worry about the long-term projections. In the past they have always turned out to be wrong. They have always projected shortages and everybody adjusted. If you project a surplus, people will again adjust.

Elbridge Sibley's discussion of the social sciences points out the difficulty of defining the social scientists. Dr. Sibley also believes that projections of Ph.D. production in the 1970's will be above the actual numbers.

ELBRIDGE SIBLEY: Depending on the criteria arbitrarily used to define a social scientist, the United States total can be estimated with varying degrees of precision. When we talk about social science manpower, or more simply about social scientists, we are referring to an arbitrarily defined segment of humanity and that the individuals included in it are extremely heterogeneous with respect to innumerable characteristics other than the few specified common traits. Statistics from the National Register of Scientific and Technical Personnel include four overlapping categories of people: Those who are formally trained in certain disciplines; those who are employed in certain activities; those who identify themselves as scientists; and those who have certain specialized competences.

Manpower Projections

In summarizing data from this source the following have been counted as social scientists: anthropologists, economists, linguists, political scientists, psychologists, and sociologists. The inclusion of all psychologists, although some of them would more logically be classed as biological scientists, and the exclusion of statisticians, although some of them might be considered social scientists, are admittedly arbitrary.

The National Register's statistics indicate some relevant characteristics of social scientists, and provide various bench marks for comparing them with other kinds of scientists:

1. Social scientists are a minority group among scientists: They are outnumbered by 5 to 1 by the combined total of physical, biological, and mathematical scientists; if the comparison is limited to holders of doctoral degrees, they are outnumbered by 4 to 1.

2. Social scientists are predominantly male, but 1/6 of them are women, as against 1/12 of all other scientists.

3. Social scientists seem to have on the average higher academic credentials than other scientific groups: 60% of social scientists and 33% of all others in the Registry are Ph.D.'s. Roughly equal proportions of holders of master's degrees are found in the two groups, but the percentage of social scientists with only bachelor's degrees is 5% as against 35% of the other scientists.

These contrasts are certainly partly, possibly largely, artifacts of the different criteria of scientific status used by the social science associations and by the other scientific associations whose mailing lists were the primary source of the National Register's data. But the very fact that the two groups of professional associations' criteria differ may in turn reflect a significant fact, that the social sciences have not yet developed prebaccalaureate vocational training to anything like the degree that it has been developed in some of the natural science fields, notably in chemistry which accounts for nearly half of all baccalaureate scientists in the Register.

4. Social scientists in general receive slightly lower salaries than other scientists, but the difference is much smaller than might be imagined. Median salaries in the six fields of social science and psychology range from $11,500 to $15,000; the range for the nine fields of other sciences is almost the same: $11,000 to $14,900. The near-parity of averages for the two broad categories must be discounted, however, in view of the previously mentioned predominance of holders of higher degrees among social scientists.

5. Social scientists are predominantly employed in educational institutions, while a majority of other scientists occupy nonacademic positions; the respective proportions in educational institutions are 2/3 and 1/3. The proportions vary considerably among the several social science fields, with only psychologists and economists approaching a 50-50 division between academic and other employment.

6. Social scientists were only somewhat less likely than other scientists to be receiving some part of their support from federal government funds.

The annual output of advanced degrees in the social sciences has been increasing in the past decade and a half at practically the same rate as that in the other sciences, and projections prepared by Donald S. Bridgman for the Commission on Human Resources[1] indicate that the rates of growth in the two

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1. See ftn. 3, p. 13. Other projections are given in John K. Folger, Helen E. Astin, and Alan S. Bayer, Human Resources and Higher Education, Russell Sage Foundation, New York, 1970

broad fields will continue to keep pace with each other at least until 1975, barring unforeseen changes in factors on which the projections are based. The projections show a two-thirds increase in the output of new Ph.D.'s in 1975 as compared with 1970 for both social and natural sciences. The numbers of new master's degrees, which had increased more rapidly than those of doctorates prior to 1970, are expected to grow less rapidly in the next five years, mainly as a function of the changing age composition of the population. Here again the projected increases in the social and in the natural sciences are about equal - actually 57% for the former and 49% for the latter.

The recent drastic curtailment of federal funds both for the direct support of graduate students and for research grants and contracts on which universities have become so heavily dependent cast serious doubt on the prospect that Bridgman's projections will materialize.

In covering the biological sciences, Dr. Pahl clearly points to the real national demand on biological and medical manpower.

HERBERT B. PAHL: In the area of manpower in the life sciences the emphasis is on biomedical manpower. In the NIH report, "Biomedical Research Manpower for the Eighties" (NIH, 1968) it was stated, "The future growth of health research is the cardinal determinant of the need for trained biomedical manpower. Manpower is needed for:

- staffing medical schools and other health professional schools
- providing faculty for biomedical components of graduate schools and advanced undergraduate education
- staffing specialized biomedical research institutes and centers

1. By 1985, 150,000 professional workers will be needed for biomedical research, education, and related service activities.
2. Ph.D.'s will compose a steadily increasing share of biomedical research manpower.
3. Staffing new medical schools and graduate schools, and providing for expansion of existing schools constitutes a major foreseeable manpower need.
4. National interest focuses on the need to enlarge the supply of health manpower for health services and delivering these services to the people."

One thing is clear We will need more trained people to meet these future needs. The question of how many more — the question that the Administration now asks through the Bureau of the Budget — is the difficult one to answer. Unfortunately, it is not possible yet to project accurately needs in any area for needed manpower.

The concept of absolute manpower "demand" seems inappropriate. What can be discussed is the expected "utilization" of doctoral scientists with the realization that the magnitude and nature of this utilization will be affected by the available supply. The larger the relative supply, the more varied the types of activities for which Ph.D. scientists will be used. Furthermore, in periods of short supply, some tasks ordinarily undertaken by doctorates will simply not be fulfilled or will have to be redesigned so that professionals with lesser educational background can carry out part of the overall effort.

Manpower Projections

Difficult as these utilization and supply projections are for the total doctorate group, they are even more difficult to make on a field of science basis, and yet more so on a discipline basis. The numbers of doctoral bioscientists in NSF Scientific and Technical Register for 1968 show 298,000 registered scientists; of these 22,300 were in the biosciences, 2,300 in agricultural sciences, and 7,400 had professional medical or other degrees. This represents 32,000 and is equivalent to 0.3% of all professional workers in the U.S. and 0.03% of the total labor force.

Based on certain assumed funding growth rates, Dr. Alberty shows that the current situation will change to one of shortage in the late 1970's unless Ph.D. production increases in the late 1970's.

ROBERT A. ALBERTY: In order to get a better understanding of the supply and demand of doctoral chemists and physicists, I have compared the National Registry data for 1955 to 1968[1] with the doctoral production data of the National Research Council.[2] Although there are problems with the completeness of the National Registry data, immigration, emigration, field transfers, and definitions of fields, analysis of the available data for 1955 to 1968 provides some basis for extrapolation. 1955 to 1968 was a period of rapid growth of federal funding of research and development, but the employment of doctoral chemists and physicists did not increase that rapidly — partly because of the long time required for training. For the 1969 doctorates the

1. American Science Manpower, 1954-5, 1956-58, 1960, 1962, 1964, 1966, and 1968, National Science Foundation.

2. National Research Council, Office of Scientific Personnel, "Doctorate Recipients from United States Universities, Summary Reports for 1967, 1968, and 1969," Washington, D.C.

median time lapse from baccalaureate to doctorate was 5.4 years for chemistry and 6.3 years for physics.[2] Table I shows the growth of jobs in educational institutions, government, and industry, as compiled from National Registry data for 1960 and 1968.

Table I

Growth in Jobs for Doctoral Chemists and Physicists from 1960 to 1968

		Educat. Inst.	Govt.	Ind.	Other	Total
Chemistry	1960	6,087	1,451	10,642	1,284	19,464
	1968	9,895	1,631	14,473	1,480	27,479
	%/yr.	6	1.9	4	1.7	5
Physics	1960	3,094	640	2,714	1,282	7,730
	1968	8,364	1,306	3,697	719	14,086
	%/yr.	13	9	4	-7	8

The rate of growth of employment by educational institutions may be compared with the growth of enrollment as recorded by the Office of Education;[3] for 1960-68 the degree credit enrollment increased 12% per year in two-year colleges, 7.5% per year in four-year colleges, and 10% per year in graduate schools. The Office of Education Projections for 1977-78 indicate that from fall 1968 to 1977 these growth rates are expected to average 5.4% per year for two-year colleges, 3.7% per year for four-year colleges, and 6.1% per

3. Office of Education, "Projections of Educational Statistics to 1977-78," U.S. Government Printing Office, Washington, D.C., 1969.

year for graduate schools. In my calculations I am going to assume that in the period 1968-1980 the number of jobs for doctoral chemists and physicists in educational institutions will increase 4% per year. This rate is considerably lower than for the preceding eight years but is the rate required to maintain the ratio of doctoral chemists and physicists to students in two-year and four-year colleges constant. This estimate is conservative in the sense that this growth rate may be met even though additional jobs do not grow at this rate. It is expected that a number of jobs will result from the replacement of staff not holding doctorates by doctoral chemists and physicists. The estimate of 4% per year is high in that it is applied to postdoctoral and research positions in colleges and universities as well as numbers of regular faculty.

The rate of growth of employment of doctoral chemists and physicists by industry was 4% per year in the 1960-68 period, and I assume that this rate, which is about the rate of growth of GNP in constant dollars, will continue in the 1968-80 period. The 1960-68 period was one of short supply of doctoral scientists and of great pressure to increase academic employment because of rapidly increasing enrollments. This estimate of 4% per year increase in jobs for doctoral scientists is conservative in the sense that some of the new jobs may be created by replacement of bachelor or masters chemists and physicists by doctorate holders.

Table II shows that the number of employed doctoral chemists increased from 14,000 in 1955 to 29,000 in 1968. This is a rate of 5% per year. The third column gives the doctorate production rate, and the fourth column the number of doctorates produced thirty years earlier. This is taken as an estimate of the number of retirements and deaths for each year. Adding the doctorate productions in 1955, 1956, and 1957 to the number of employed doctorals in 1955 and subtracting the assumed retirements in these years give the expected number of doctorates in 1958. This number is 2,245 larger than the National Registry actually counted, and so this is called a Loss. The large Loss of 1955 to 1958 is more than made up in the next two-year period, and so probably the response on the 1958 survey was not as complete as in 1968.

Table II

Employment of Doctoral Chemists

	Empl. Doct. (Natl. Reg.)	Doct. Prod.	Retire	Loss
1955	14,067	1,010	209	
1956		980	252	
1957		1,042	215	
1958	14,178	959	253	2,245
1959		1,077	249	
1960	19,464	1,105	297	-3,752
1961		1,139	329	
1962	19,566	1,139	328	1,516
1963		1,254	382	
1964	21,789	1,301	415	540
1965		1,414	383	
1966	23,915	1,571	455	-209
1967		1,744	504	
1968	28,973*			-2,702
TOTALS		15,735	4,271	-2,362

*23,778 have doctorate in chemistry.

For chemistry the losses fluctuate a good deal and so perhaps only the net loss over the thirteen-year period (-2,362) is significant. A negative loss represents, of course, a gain of Ph.D.'s over the U.S. production: an average gain of 180 Ph.D.'s a year. One source of gain is immigration of doctoral chemists and another is transfers of doctoral scientists from other fields. The National Registry data for 1968 show that of 27,570 persons receiving doctoral degrees in chemistry, 3,792 (13%) left the field of chemistry, and of 28,973 doctorates employed in chemistry, 5,185 (18%) entered the field with doctorates in other fields.

Table III gives a projection of the supply and demand for doctoral chemists for the period 1968 to 1980. The number of employed doctorates which was 28, 973 in 1968 is projected ahead at a 4% per year rate. The annual doctorate productions for 1968 and 1969 are known, and the remaining doctoral productions are estimates based on the assumption that federal support of graduate programs may be somewhat smaller in real dollars for the next several years. The approximate losses or gains are small compared with the doctoral production rate. The tightness of the job market at present may indicate that job opportunities have not increased by 4% this year.

Table III

Projection of Employment of Doctoral Chemists

	Empl. Doct.	Doct. Prod.	Retire	Loss
1968	28,973	1,782	406	149
1969	30,200	1,947	464	283
1970	31,400	1,800	524	76
1971	32,600	1,800	650	-150
1972	33,900	1,800	591	-291
1973	35,400	1,800	506	-106
1974	36,800	1,800	469	-169
1975	38,300	1,800	292	8
1976	39,800	1,800	322	-122
1977	41,400	2,000	425	-25
1978	43,000	2,200	606	-106
1979	44,700	2,400	941	-341
1980	46,500		1,050	
TOTALS		22,929	7,246	-794

By about 1977 an increased doctoral production would be required according to this calculation. Since the average registered time in graduate school was 5.0 years for the 1969 doctoral chemists, this would presumably require an increase in first-year graduate enrollment in 1972 as compared to 1970 and 1971.

A growth rate of jobs for doctoral chemists of 4% per year may be achieved even if total jobs for professional chemists do not increase at this rate.

Manpower Projections

Table IV shows the total employment of chemists in 1968 from the National Registry. In order to be included, a chemist must have a bachelor's degree and current employment in the area of chemistry or ten years of professional experience in an area of chemistry. In order to allow for the fact that some of the nondoctorate chemists employed by educational institutions are graduate students, I have subtracted all chemists employed by educational institutions who are below age thirty. This table indicates that there are only about 2,000 jobs for chemists in educational institutions that are not filled by holders of the doctoral degree. However, there must be many more people teaching chemistry at the post-high school level who are not picked up by the National Registry. For the other employers of chemists only about one-fourth of the jobs are held by doctorates, and so it would be possible to employ a considerable number of doctoral chemists in upgrading some of these jobs.

Table IV

Number of Chemists by Employer, 1968

	Total	Doctoral
Educat. Inst.	12,230	9,895
Industry	53,291	14,473
Government	6,468	1,631
Other	5,171	1,480
TOTAL	77,160	27,479

Table V shows the number of employed doctoral physicists, as identified by the National Register. This table, which has been constructed in the same way as Table II for chemistry, shows that there was an influx of doctoral scientists into employment as physicists in the 1958 to 1960 period. In the next six years the increases in employed doctoral physicists are given quite accurately by this oversimplified calculation. The influx in 1968 is harder to understand and probably represents a more complete survey and changing definitions of fields.

Table V

Employment of Doctoral Physicists

	Empl. Doct. (Natl. Reg.)	Doct. Prod.	Retire	Loss
1955	5,483	507	51	
1956		485	86	
1957		462	80	
1958	6,495	496	93	225
1959		515	96	
1960	8,076	531	106	-759
1961		597	111	
1962	9,080	710	115	-93
1963		818	133	
1964	10,286	864	124	74
1965		1,046	138	
1966	11,850	1,049	140	84
1967		1,295	159	
1968	14,311*			-416
TOTALS		9,375	1,432	-885

*11,955 have doctorate in physics or astronomy.

Manpower Projections

Table VI, which corresponds with Table II for chemistry, is based on the assumption that jobs for doctoral physicists increase 4% per year starting in 1968. The annual doctoral productions for 1968 and 1969 are known,[2] and the remaining annual doctoral productions are assumed. Since federal funding has not grown as rapidly as inflation and other increased costs of doing research, the assumed annual doctoral productions have been decreased to a level such that there is not a significant difference between supply and demand.

Table VI

Projection of Employment of Doctoral Physicists

	Empl. Doct.	Doct. Prod.	Retire	Loss
1968	14,311	1,422	154	679
1969	14,900	1,452	156	696
1970	15,500	1,200	144	456
1971	16,100	1,000	186	214
1972	16,700	900	155	45
1973	17,400	900	130	70
1974	18,100	900	63	137
1975	18,800	900	43	57
1976	19,600	900	71	29
1977	20,400	1,000	148	52
1978	21,200	1,100	224	76
1979	22,000	1,200	319	-19
1980	22,900		421	
TOTALS		12,874	2,214	2,492

The "loss" calculated in this way for 1968 and 1969 indicates that the number of jobs increased more rapidly than 4% per year in this period. This should be reflected in the National Registry data for 1970 when that compilation has been completed. The loss of 456 for 1970 indicates very approximately the excess of doctoral physicists over jobs that would result from a 4% increase in jobs between 1969 and 1970 with the implicit assumptions about immigration, emigration, and field transfers. A more complete calculation has been carried out by Dr. Wayne R. Gruner[4] of NSF, with similar conclusions for 1970-1971.

By about 1977 an increased doctoral production would be required if jobs increase at a rate of 4% per year. Since the average registered time in graduate school was 5.8 years for the 1969 doctoral physicists, this would presumably require an increase in first-year graduate enrollment in 1971 as compared with 1969 and 1970. Thus it would appear that there is a very real danger of overreaction to the current job market.

Table VII shows the number of physicists by employer in 1968. The total number of physicists in educational institutions was corrected for graduate students in the same way as Table IV for chemists. These tables bring out a marked difference between the two fields: 77% of employed physicists have doctoral degrees compared with 36% for chemistry. This may mean that there is not as much opportunity for upgrading jobs to the doctorate level in physics as in chemistry.

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4. Wayne R. Gruner, Talk to American Institute of Physics, Spring 1970.

Table VII

Number of Physicists by Employer, 1968

	Total	Doctoral
Educat. Inst.	11,179	9,286
Industry	9,436	5,577
Government	3,803	3,765
Other	1,775	1,441
TOTAL	26,193	20,069

So many simplifying approximations have to be made in calculations of this type that it is not possible to have much confidence in projections over the period of a decade. Nevertheless it is important to try to visualize how the manpower situation will develop in all fields. Too great a production of doctorates who have quite specific ideas as to the types of jobs they seek can lead to disappointment if these jobs do not exist at a later time. But overreaction can lead to later shortages. Comparison of chemistry and physics shows that there are significant differences in the manpower situations in even closely related fields.

We have been dealing here with the total numbers of jobs for doctoral chemists or physicists. Even if the total numbers are in balance, there is the question of distribution with respect to subfield.

At the present time many people in government, industry, and the university are involved in understanding the manpower situation. Michael Crowley points out the dangers of not relying sufficiently on manpower experts.

<u>CROWLEY</u>: I would like to take some exception to encouraging people in other fields to make manpower analysis. While it is good that scientists are interested in manpower, one can get into some danger. One cannot assume that all the sciences will grow at the same rate, so that science growth cannot be pegged to the GNP. For planning purposes or for guidance purposes, you have to use a more consistent economic framework, including the overall economy in order to make projections. For instance, the increased utilization of Ph.D. chemists by upgrading employees of chemists without the Ph.D. to those with a Ph.D. makes the assumption that employers want to upgrade. A recent study done in the Labor Department questioned employers about this. They told us there were certain requirements they had for Ph.D.'s and certain requirements they had for non-Ph.D.'s and they desired to maintain some kind of relationship between the two.

<u>ALBERTY</u>: I agree with you. I think that people in the Labor Department ought to look at manpower in the science fields, and I think it is also important for people inside the scientific fields to also look at the manpower situation. There are all sorts of "booby traps" about definitions of manpower, which really are very difficult to handle. The Office of Education trend analysis indicates that the national production of the baccalaureate in both chemistry and physics will decline in the next decade. We are presently producing more baccalaureates than we will at any time during the next decade. If this decline continues, and it is not unrealistic to expect that it will continue, then there are just not going to be enough bachelors chemists and physicists to fill some of these job opportunities. The employers are going to have to adjust to that situation. If the doctorates are not produced, maybe there will be more bachelors. The science marketplace reflects

a little bit of the level of the students' educational aspirations and what the employers want, and both of these have to reach an equilibrium.

Dr. Charles Falk, the Director of the Division of Science Resources and Policy Studies of the National Science Foundation, makes some general comments on the reasons for concern about scientific manpower. Dr. Falk stressed the need for hard facts before reacting to anecdotal information. A recent NSF study directed by Dr. Falk concluded that by 1980 it is not likely there will be a mismatch between supply and utilization of Ph.D.'s, though a considerably larger number of Ph.D.'s would be employed in different positions than those held today by most doctorates.

DR. CHARLES FALK: Some aspects of the manpower problem while known to many symposium participants, require repetition, because it is too easy to forget them in the crisis atmosphere which exists today. The fact that there is a problem is evident from the many special meetings on scientific manpower which have taken place during the last year.

Deep concern exists among various groups. Obviously there is concern by the students. In the first place the students are deeply concerned about the possibility of not finding a job at all, even though this eventuality is somewhat rare. They are much more concerned about not finding a job which will match their aspirations. This apprehension is very valid since frequently these days there is a mismatch between job opportunities and student aspirations. Faculty and university administrators are equally concerned. They have the responsibility of planning for the future of their particular academic institution both with respect to magnitude and also in regard to the curriculum called for by the future professional activities of their students. Government planners are concerned because, without any doubt, the government has taken a major role in graduate education in science and engineering through its various funding programs. Under present circumstances the big question faced by government is what its future actions should be with respect to scientific manpower.

People in most of these sectors are also very concerned that we do not talk ourselves into a situation of panic, where we react more emotionally to anecdotal information instead of rationally to hard facts. This is very easy to do in a transition period which produces stresses and strains. The reaction of government agencies, universities, state legislatures, etc., frequently is more affected by the type of atmosphere which is created through generalized articles or other statements than by the facts, especially when the facts are not always immediately available, as is the case with some aspects of this problem. The reactions of decision makers can actually be the opposite of what people expect them to be when they make certain statements. I believe it to be very important to try to assess the situation as it is on the basis of as many factual data as can be obtained. This is especially difficult now since the picture keeps changing so rapidly. I think that we have to try as hard as possible to be objective and not to overreact to the scientific manpower situation. We must realize that sometimes manpower data are not available, and that, if at all possible, we should take steps to get the data before we form conclusions and plans of action.

In 1969 the National Science Foundation carried out a study to assess the likely supply and demand of science and engineering doctorates in 1980.[1]

1. National Science Foundation, "Science and Engineering Doctorate Supply and Utilization 1968-1980," NSF 69-37, U.S. Government Printing Office, Washington, D.C., November 1969.

Manpower Projections

This study covered the total aggregate of doctorate scientific manpower including those in the social sciences. The details of the study can be found in the publication, NSF 69-37. Various assumptions were explored to calculate possible supplies and utilizations in the year 1980. A whole range of results were obtained depending on the assumptions.

The conclusions of the NSF study are the following: The likely supply in 1980, based on past Ph.D. production rates, is 350,000 doctorates. However, this number is probably the absolute maximum. Information on the real and alleged job difficulties of present doctorates will produce a feedback effect on the supply of new graduate and undergraduate students and fewer students will go into science and engineering. Thus the supply in 1980 is probably going to be at least 10-15% smaller than the 350,000 predicted in the NSF study. This 300-350,000 doctorate pool must be compared to the various calculated utilizations figures which vary between 280-380,000 depending on the assumptions and methodologies used. Some of these assumptions take into consideration the utilization of Ph.D.'s in some areas where they had not been utilized to anywhere near their full extent, such as in two- and four-year colleges or in nonacademic, non-R&D activities. These new utilization patterns, which are already being experienced, will result in an increase in the percentage of Ph.D.'s in these types of jobs. The study concludes that the likelihood for a bad mismatch of supply and utilization is small, but not impossible. Thus it is recommended that no external policy steps be taken to affect the supply system. It can be assumed that some of the feedback effects will be sufficient to produce a correction which will probably assure a long-range supply-demand balance. In view of this correction, policy and budget steps taken to reduce graduate enrollment now may well produce shortages five years from now when the effect of these steps will become evident in the annual number of new doctorates.

Philip Abelson, Editor, Science magazine, warned about not recognizing the serious nature of the present-day manpower situation. In the rapidly changing employment situation we find ourselves in today, Dr. Abelson recommends a Gallup-type sampling of employment patterns in order to get meaningful statistics. Unlike Dr. Falk, Dr. Abelson believes that anecdotal information combined with good judgment must be used to appraise the current manpower crisis.

PHILIP ABELSON: There is little doubt that in the long term, scientists and engineers will be of crucial importance to the life of this country. As time goes on, our dependence on these disciplines will increase. However, today there is quite a dislocation in the supply and demand for scientists and engineers. Both at the universities and in Washington there is a tendency to play down the extent of the dislocation. This minimization does not seem very intelligent because what it does is delay making the necessary adjustments. If you paper over a problem, the hard thinking necessary to resolve the difficulty is not done.

It is very difficult to get hard figures about the present employment situation. The manpower statistics lag behind a couple of years, and we haven't as yet established any really good Gallup-type poll to obtain the necessary information. We ought to have such a poll in order to know what the current situation is. Presently there are a few indexes, but nothing very good. With an expenditure of a relatively small sum of money we could be much better informed. At present, if you really want to know what is happening, you must lean on anecdotal information whether you like it or not.

Manpower Projections

The anecdotal material is impressive. For example, a short while ago Science magazine had a call in answer to an advertisement for a proofreader. The man applying had a Ph.D. in physics and had been a physicist employed in a space-related activity. The personnel manager at Science was surprised by this application and quoted a ridiculously low salary. He thought the applicant was overqualified, but the physicist persisted. He wanted to be considered. "That would feed me," he said.

A professor at Carnegie-Mellon, which is a fine research-oriented university, mentioned that he was having unusual difficulty in placing his postdoctorals. One of his students had applied to a small college, confident that by lowering his sights he would get a job. The student found out that there were 300 applicants for that job in the small college. In the Carnegie Institution of Washington there is a department of embryology where biochemical research as well as molecular biology and embryology research is conducted. The department has about 10 staff members. Presently there are 300 applications from scientists who have applied for a position there.

This moment is a rough time to get a job. The job shortage is not likely to continue indefinitely. We could overtalk it, but we ought to face this thing and really determine what the situation is and whether it is necessary to make some changes.

Dr. Richard B. Freeman is an Assistant Professor of Economics at Harvard University and has been studying scientific manpower from a market viewpoint. Dr. Freeman points out that scientific planners have underestimated the responsiveness of the scientific and engineering market to money incentives. In addition, Dr. Freeman points out the time lag in the decision of students making scientific career choices and graduation four or five years later.

Chapter 1

This naturally introduces a cyclic shortage-surplus cycle.

RICHARD B. FREEMAN: **The discussion of science and engineering manpower ten** years ago shows a completely different situation than we now have. **In 1962** President Kennedy labeled the lack of Ph.D.'s in engineering, science, and mathematics as "one of the nation's most critical problems," and there was a great concern about this issue. Some people at that time, however, believed that this shortage was not a major problem. There is a very interesting quote from a very conservative senator, who said, "There are 20 or 30 million hungry Americans and we shouldn't worry about science and engineering. Instead we should be worrying about these people."

The situation has changed today. Whether it has changed for the better or for the worse is a value judgment. One can predict, however, that ten years from now it will change again. I think there is an underlying structure that explains why we have this kind of problem coming up every few years. Sometimes there is a concern with a shortage, sometimes with a surplus.

I would like first to discuss the structure of the scientific manpower market that causes these upsets every few years. There are two problems to consider concerning the scientific manpower market. First, why has there been this sudden alteration in the supply and demand situation? It's occurred in the last four or five years. Second, what is the mechanism by which this market reacts to national policies? It is very important that this mechanism be understood in order to devise rational policy.

Why did the impending shortages of the early 1960's fail to develop? If you look back at projections of R&D spending, despite the slowdown of the last two or three years, you find that's not the reason. It wasn't that the level of R&D wasn't predicted correctly; in fact the projections of R&D funding were about on the mark. So lack of support wasn't the reason for this shift from shortage to "surplus." The reason for this sudden change to surplus is the substantial supply response on the part of young people. In 1962, President Kennedy's science advisory committee gave a goal, which they considered very difficult to obtain, of 5,700 Ph.D.'s in engineering, mathematics, and physical sciences for 1968. The actual number of Ph.D. graduates in this field in 1968 was about 7,500, which surpassed the Kennedy goal by 31%. This may have been one of the few times in the history of the country that a goal of this kind was surpassed. The moral of this is that the scientific manpower market is an extremely responsive mechanism to federal policies and to economic needs. It is far more responsive than people back in the 60's were willing to recognize.

What mechanisms govern the response of the science manpower market? Research in the area of supply and demand of scientists and engineers indicates that economic incentives are a very important determinant of behavior. Lifetime earnings, opportunities, and fellowship support account for most of the increase in Ph.D.'s in the past twenty years. Underlying the overall rise is a very high rate of return. The return for investing in a doctorate degree in 1960 was on the order of 15%, and that is as good a return as many companies can get on their capital. The salaries of scientists and engineers from 1956 to 1966 increased more rapidly than that of any other group of workers in society, including construction workers. The market was getting very much better and naturally students were responding. At the same time, the government was pouring money in to support graduate studies. Graduate student support changed drastically in the past few years, compared with the 1920's, 1930's, and 1940's. Students responded to these economic incentives. The economic forces explain not only the overall increase in the number of Ph.D.'s and why we more than attained President Kennedy's goal, but also which fields grew the most rapidly.

In 1960, the National Academy of Science did a survey of doctorate scientists. Calculations of the lifetime earnings of the different fields show that engineering and mathematics were highest. These fields have increased the most rapidly since 1960. To illustrate this economic responsiveness, one can plot a graph of the proportion of Ph.D.'s in mathematics versus the relative salary of mathematics Ph.D.'s to other Ph.D.'s five years earlier. Excepting the World War II period, they are very closely related. The increased supply of mathematics Ph.D.'s is determined by the relatively increased salaries for mathematicians. In 1935 mathematics was the lowest paying Ph.D. field out of twenty or thirty fields. Today it is the fourth or fifth highest paid and one of the highest paid in the sciences. Thus, there is a very substantial supply responsiveness in this market. (Figure 1.)

Another issue in examining the scientific labor market is the question of lags in supply. There is a four- to five-year or longer training period. With a time delay of this kind, students make decisions on the basis of conditions when they enter school. When they graduate years later, the market may have changed greatly. This creates a feedback system which leads to cyclic changes in the supply market. A lot of discussion of scientific manpower in research and development problems have misconstrued cyclic phenomena for long-term trends.

The cyclic mechanism operates as follows: In a given year with high salaries and good opportunities, a lot of students decide it is a good field and they choose to enter it. Four or five years later they graduate and, if

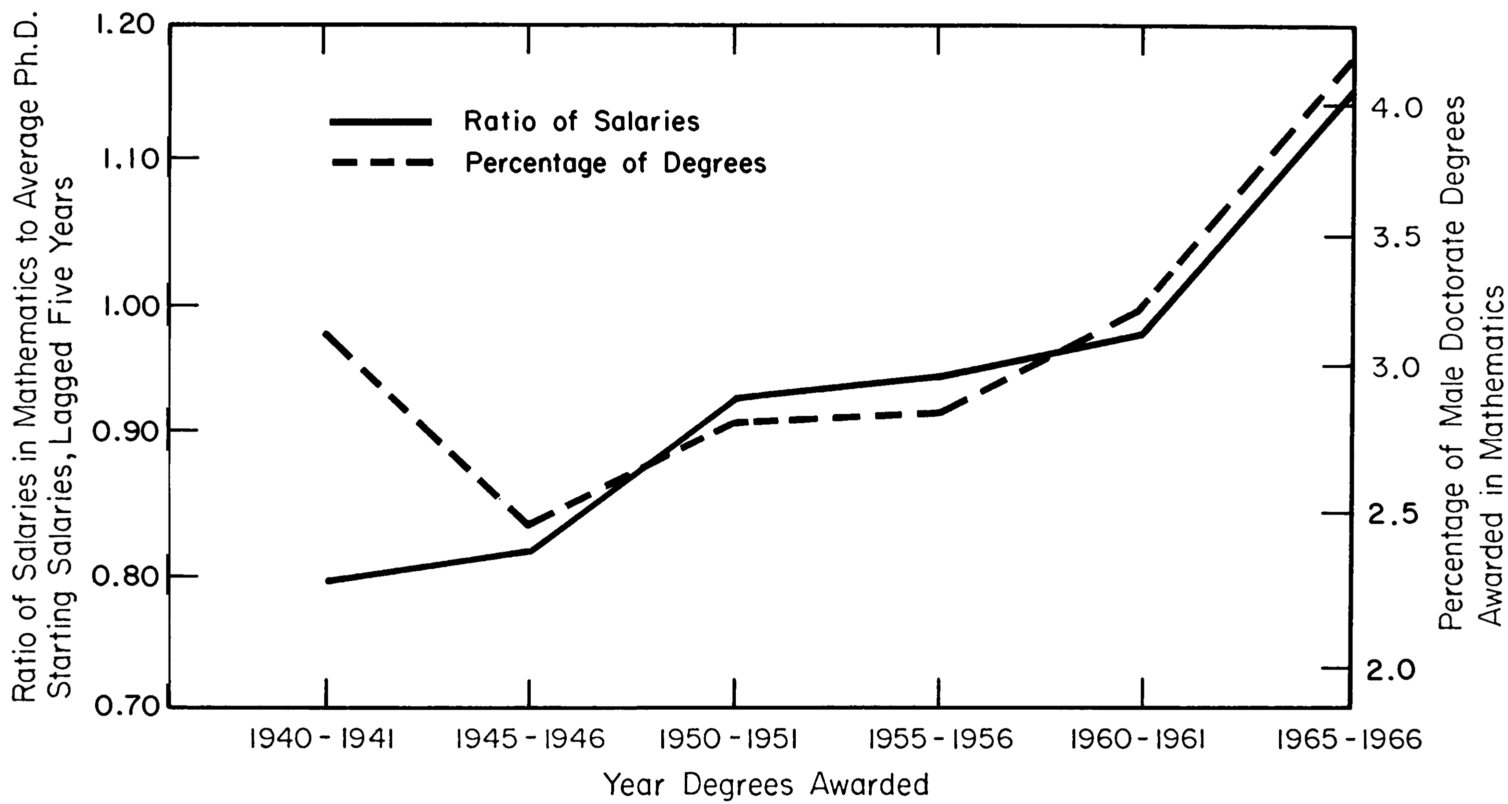

Figure 1. The Proportion of Ph.D. Degrees Awarded to Males in Mathematics Compared to the Ratio of Starting Salaries in Mathematics to the Average Doctorate Starting Salary Five Years Earlier, by Quinquennium, 1940-1965.

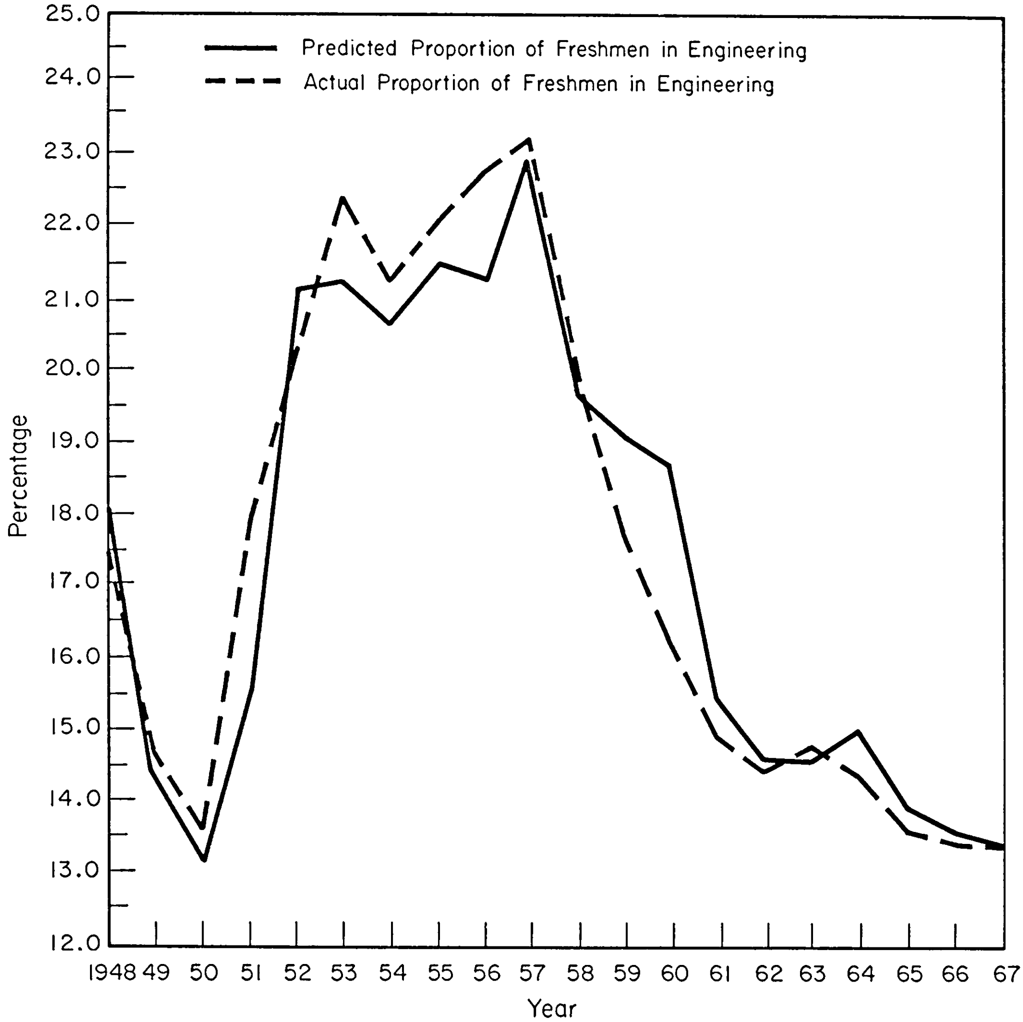

Figure 2. The Percentage of Freshmen in Engineering Compared to the Proportion Predicted by the Cobweb Supply Equation, 1948-1967.

everything else is the same, this enormous increase in supply reduces salaries, reduces the job opportunities,and hurts the job market. The next response of students at that period of time, therefore, will be to go into other fields, and the thing goes on. The graph of percentage of freshman choosing a B.S. engineering program has changed rather drastically over the years. (Figure 2.) At one time it was 25% of the freshmen; today it is about 10%. It closely follows what one would predict on the basis of the salaries of engineers versus the salaries of all professional workers in the society one year before. The percentage jumps up and down with salary. The supply is a cyclic phenomenon and now it is in a downswing. It probably will be up, say, ten years from now. This model, based on relative salary at the time a student chooses a career, in a statistical sense explains very well the fluctuations in engineering and also the fluctuations in the discussion of engineering shortage and surplus. At one of these down points in supply, everyone is concerned about a shortage. At one of the top points, the concern is about a surplus. This sample model ignores the sudden shifts in demand now occurring and must be incorporated in the model. In determining public manpower policy and in understanding the market, both the rather economically responsive part of the suppliers and the fact that the lag structure leads to cycles that go on for many years must be considered.

Hugh Folk, who is a Professor of Economics at the University of Illinois, points out that extrapolations of scientific manpower are very dangerous. Important trend factors often cannot be seen or appreciated until many years into the projections. Dr. Folk believes the outlook for engineers is poor due to the present concentration of engineers in relatively few industries, two of which, aerospace and defense, are likely to see a continued decrease *in support in the 1970's.*

HUGH FOLK: A regression equation can be used to obtain the relationship between master's degrees in a given year to the earlier earned bachelor's degrees. Very little of the increase in production of master's degrees and doctorates during the 1960's was related to fluctuations in the number of bachelor's engineering degrees. The increase was trend dominated. There was a steady increase in masters and Ph.D.'s year by year. In 1968, for instance, using the equation fitted to the years 1955-62, the predicted value for the total number of engineering Ph.D.'s was about 1876. The actual number of Ph.D.'s produced was 2903. In other words, the regression equation was a good fit for the late '50's and early '60's but the trend of going for an advanced degree kept shifting up. These old equations give very poor estimates or predictions of current manpower supply. The trend of increased graduate degrees was missed in the predictions and this led to underestimates of the number of graduate degrees to be produced.

The output of Ph.D. engineers tripled from 1958-68. In 1958, for instance, about 3% of bachelor's degrees were going on to get Ph.D.'s. In 1968 about 9% were going on. In 1958 19% of the bachelors were going on to get a master's. In 1968 about 41% were going on. For the increments in the personnel entering the engineering profession, about 2/5 have the master's degree, and of these about 14% have the Ph.D. The total of all engineers, of course, has very much smaller proportions of graduate engineers. This fact is something that often can deceive us. The ample opportunities that Ph.D.'s had in finding jobs until the late 1960's reflected the fact that a relatively small proportion of engineers had graduate degrees. Even in the early '60's comparing the lifetime earnings of engineers with bachelor's, masters, and doctors degrees clearly indicated that something was wrong. For instance, in 1963, for nonsupervisory research engineers and scientists the present value of lifetime earnings of a B.S. or M.S. was $170,000. For engineers who went on to get a Ph.D. it was $160,000. In other words, an engineer had a reduction in income for getting his Ph.D. In 1962 for chemical engineers with a B.S. or M.S. the earnings were $158,000 and for the Ph.D. it was $149,000. This was a clue that an economist should have seen. There was in fact no great unsatisfied demand for graduate degrees reflected in earnings. At that time, however, employers said they were desperate for Ph.D.'s and masters in engineering. They weren't, however, paying a premium that reflected the additional foregone earnings and the costs of getting these graduate degrees.

What is the outlook for graduate engineers? Industry does not hire an engineer because he is nice to have around, but because he is useful. Engineering employment is concentrated in a few industries: electronics, aerospace, instruments, and ordinance. The growth of these industries is critical to the employment of graduate engineers. There is simply not enough work outside of these industries to provide a significant number of jobs for graduate engineers. The desirability of engineers of various kinds depends on the subjective opinions of their employers, what employers think they are worth, not necessarily their objective performance. In the last few years we have seen a substitution of men with graduate degrees in engineering for men with bachelor's degrees. And at the other end, because of the shortages of bachelor's degree engineers, there has been a substitution of nonbachelor's engineers and technicians for traditional bachelor engineer jobs. Employers act like good rational profit-maximizers and will substitute among these various grades until the ratio of their marginal revenue productivities and salaries are the same. In other words, if you have got to pay a premium for a Ph.D., you have got to believe his productivity is higher than the productivity of a bachelor's degree.

The critical assumption for manpower projections is the assumption that engineers are concentrated in relatively few jobs. This is demonstrable. Ph.D.'s in engineering in industry are employed in relatively few industries. These industries are sick, they are not growing, and most of us hope they won't grow in the future. An increasing number of engineers also hope they won't grow. The successful aerospace firm is becoming rare. Lockheed is close to insolvency, and unless Congress bails it out, it may be finished. The SALT talks are presently under way. Serious disarmament talks were not taking place in any previous time period. Although the defense industries have great technological potential, there is little reason to believe that, in the coming years, the government is going to finance the research necessary to realize these potentialities. The demand for engineers in the aerospace and defense industry is not going to grow rapidly.

In 1968 there was a stock of 20,000 Ph.D.'s in engineering. The annual production of Ph.D.'s is 1500 with an attrition of 2%, thus the net increase in the stock of Ph.D. engineers is about 5.5% per year. A modest factor for inflation and real salary increases is 4%. Assuming no increase in productivity for the individual Ph.D. engineer, and the same share of total R&D spending going to the employment of Ph.D. engineers, the necessary increase in R&D spending to justify the employment of these additional Ph.D.'s is 9.5% per year. It is not likely that R&D spending will increase at this rate and this leads to a possible surplus of Ph.D. engineers.

Manpower Projections

Dr. Russell G. Meyerand, Jr., is Director of Research at United Aircraft Research Laboratories. Recent cutbacks in aerospace and defense have cut engineering manpower. This could seriously affect both our national defense posture and our balance of international trade.

RUSSELL G. MEYERAND, JR.: Today we are facing a situation in which the specter of significant underemployment of scientists and engineers looms close at hand. The aerospace industry, of course, is the one with which I am most familiar. As of March 1970, industry-wide aerospace employment has declined 93,000 persons from the 1969 average, and is still declining. This figure, of course, represents all levels of employment. It is difficult to obtain a breakdown as to categories. However, it is estimated that 6,000 of this decline are engineers and scientists.

It was reported in a recent Newsweek article that 2.5% of the Ph.D. graduates in physics for the past three years are unemployed. Another article reported that 18% of last year's physics Ph.D. graduates received no job offers in their field. This contrasts sharply with the demand in the very recent past that we all remember when most, if not all, doctoral or master's candidates could obtain as many job offers as he or she was willing to take interviews. This state of underemployment represents a serious waste of national talents and capability and can in the long run put the United States at a serious disadvantage, both in the commercial worldwide markets with such rapidly advancing countries as Japan, West Germany, and Russia, as well as seriously affecting our national defense posture.

A fact not appreciated by many is that nearly 10% of the United States gross foreign sales comes directly from aerospace goods. Sales of these aerospace goods abroad led all other single categories of manufactured products in shipments to foreign countries last year. If this source of economic flow to the United States were to be drastically curtailed, our balance of payments would become even more seriously out of balance than they already are.

Mr. Stephen Kaiser is a graduate student in the Mechanical Engineering Department at MIT. Mr. Kaiser points out that the poor planning of national science and engineering programs in space and highways has led to sharp changes in demand for scientific and engineering manpower.

STEPHEN KAISER: Two examples of where we've failed to anticipate trouble and have fouled ourselves up are in the space and highway programs. Space funds have risen from about $400 million in 1960, peaked out at $5.9 billion in 1965, and then dropped off precariously to $3.3 billion this year. This suggests that, by extrapolating this curve, the space program may have only a ten-to twelve-year overall lifespan. What a remarkable development, since everyone has been saying we are living in the "Space Age!"

Even more important is the employment curve. The total space program employment was 58,000 in 1961, peaked at 377,000 in 1965 and dropped off to the 1970 estimates of 138,000. The funding curve and the employment curve follow each other. It is important to realize that the 138,000 still in the space program include a good number of maintenance personnel kept on by the protective unions. It has been the white-collar engineers, usually unrepresented by unions, who are being given the pink slips. Cutbacks at a major aircraft builder in New York have resulted in a 1/6 reduction of their 30,000 work force this year. The first wave of cutbacks are going to be white-collar engineers.

Manpower Projections

There are qualitative signs in our society showing dissatisfaction with the space program and the scientific programs associated with it. Financial writer Donald White of the Boston Globe comments: "The whole darn mission of Apollo 13 boils down to two astronauts scooping up less than 100 pounds of rocks and bringing them back home." Either that's true or the scientists have not been getting the message across about what they're really achieving. Unfortunately, one suspects that Mr. White may be pretty close to the truth. Victor McElheny of the Boston Globe reports the case of a Houston gas station attendant's wife who commented to her husband on the lift-off of Apollo 13, "Well, they're sending up three more of those idiots today."

Contrast this with the atmosphere toward space and science only ten years ago. Everybody was quite convinced of the necessity of the space program; today people are referring to astronauts as idiots. One may say these are two isolated examples; however, it reflects a basic changing mood of America. For example, Myron Tribus, Assistant Secretary for Science and Technology of the Department of Commerce, commented at MIT this spring that "America has gone on an antitechnology binge."

The highway program is another good example of how local citizens have banded together and have opposed new highways through their neighborhoods. These antihighway feelings have developed within the last five or ten years, leading to a remarkable turnabout in our whole road program.