Supply of Scientific and Engineering Manpower: Surplus or Shortage?

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New trends are developing in this country's supply of scientific and engineering manpower. Students appear to be losing interest in science and engineering; at the same time, there is concern about an oversupply of Ph.D.'s. Underlying the entire situation are two facts. (i) The number of men and women of college age, and hence the number of college students that need to be taught, will increase much more slowly during the decade of the 1970's than it did from 1959 to 1969; it will level off around 1980, and by 1990 it will be back to the 1970 level (Fig. 1). (ii) In the 1970's, the defense and space industries will have very limited need for new Ph.D.'s.

B.S. Degrees in Science and Engineering

The students receiving baccalaureate degrees in science (*1*) and engineering represent the manpower pool that will ultimately be responsible for carrying on that part of the nation's work which requires training in science and engineering. The total number of such degrees awarded yearly to men and women since 1953 is given in Fig. 2, which also plots the subtotal for engineering and the mathematical and physical sciences (EMP). The total number of men graduating annually in science and engineering has grown greatly since 1955, although it has tended to level off since 1960. At the same time, individual fields have behaved differently (Figs. 3 and 4).

When the B.S. degrees awarded to men (Figs. 2, 3, and 4) are expressed as a percentage of the total number of baccalaureate degrees received by men in all fields of study, the overall situation is as shown in Fig. 5; the results for men in individual fields are given in Fig. 6. These curves show that interest in science and engineering among college men has fallen off in recent years (*2*), a situation with which observers of the educational scene are familiar. However, what has not previously been recognized is the fact that this retreat from science and engineering among men began much earlier than is generally supposed. Specifically, the graduating classes of 1962 and 1963, which signaled the start of the decline, were in high school at the time of Sputnik. Thus, if Sputnik had any effect on American youth's interest in a career in science or engineering, the effect was negative.

Another way to approach the study of manpower is to consider the B.S. degrees awarded in science and engineering as a percentage of the entire population of 22-year-olds. Such data on the number of degrees earned per capita in various areas of science and engineering are given for men in Fig. 7. The significant feature here is that, in the last 11 years, the total number of B.S. degrees awarded to men in all fields of science and engineering has been 6.1 ± 0.5 percent of 22-year-old men. Within this total however, there has been considerable shifting among fields. In particular, interest in the biological and mathematical sciences has increased during the last decade, at the expense of engineering and the physical sciences.

Because the total number of men holding B.S. degrees in science and engineering has remained constant since 1958, it is possible to extrapolate figures with somewhat more confidence than is usually justified in predicting educational trends. A prediction has been made in Fig. 8 on the basis of the population curve of Fig. 1, assuming that after 1968 the number of men with B.S. degrees in science and engineering will continue to be 6.1 ± 0.5 percent of the 22-year-old males.

The number of women who graduate with degrees in science and engineering is a relatively small fraction of the total number of women who graduate from college (Figs. 2 and 5). At present, most of these women have degrees in either the biological sciences or mathematics (Fig. 9). The percentage of women with B.S.'s in science has not fallen off since 1960; this is particularly true in biology and mathematics. For women, the number of degrees earned per capita in various areas of science and engineering (dashed line in Fig. 9) more than doubled during the last decade. The reasons for these differences between men and women in science are not clear. The fact remains, however, that, while college men are showing diminished interest in these traditionally masculine fields of activity, the percentage of women in them has at least remained constant, and, in some cases, has increased.

M.S. Degrees in Science and Engineering

The M.S. degree provides a higher level of competence in modern science and technology than can be obtained in a 4-year program of study. In addition, it is the first postbaccalaureate step toward a Ph.D.

In engineering, the M.S. degree is especially important. While an engineer with a B.S. can readily obtain employment at a good initial salary (over $10,000 in 1970), he is not adequately equipped to deal with the technology of more interesting and challenging contemporary problems in engineering development, design, and so on. As a result, the master's degree, or its equivalent, is becoming more and more necessary for professional engineering work. Terminal master's programs now represent a major activity in engineering education, with increasing numbers of engineers earning the M.S.

A special situation also exists in mathematics, since the student who has received a traditional B.S. in mathematics has little that is marketable in terms of employment. However, the student who holds an M.S. in traditional mathematics is qualified to teach in a high school, in a commu-

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nity college, or in a liberal arts college that cannot attract and hold Ph.D.'s. In addition, industry seeks people with an M.S. in mathematics to work in such fields as statistics, operations research, and, particularly, computer science. The number of M.S. degrees awarded annually to men since 1952 is given in Fig. 10. These numbers are large and have been growing rapidly, as shown in Table 1.

Ratios of M.S. degrees to B.S. degrees awarded 2 years earlier in the same field are plotted in Fig. 11. These curves represent the approximate percentage of each graduating class that continues its studies to the M.S. level; however, in certain fields, notably chemistry, the biological sciences, and physics, a significant proportion of those who receive the Ph.D. degree do not bother to obtain the M.S. degree on the way. When this is taken into account, it is clear that roughly one-third, if not more, of all men who have earned baccalaureate degrees in science and engineering in recent years have continued their formal studies to at least the level of the M.S. In addition, there are substantial numbers of students, especially in engineering, who are employed full-time and who are concurrently receiving some formal training beyond the B.S. degree in part-time study, but who do not complete all of the requirements for the master's degree.

Many M.S. degrees in mathematics and the biological sciences are awarded to women, as shown in Fig. 10, even though the number is small relative to the number of M.S. degrees received in these fields by men. Very few M.S. degrees are awarded to women in other areas of science and engineering.

Ph.D.'s in Science and Engineering

The doctorate is the preferred level of preparation for those who wish to pursue an academic career in science and engineering, or a career in industrial research. The number of Ph.D.'s awarded in engineering and in various fields of science since 1952 is given in Fig. 12. The ratio of Ph.D.'s to B.S.

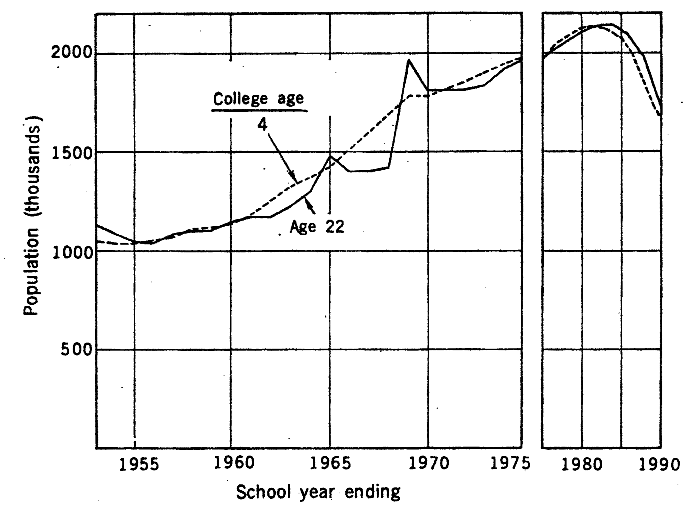
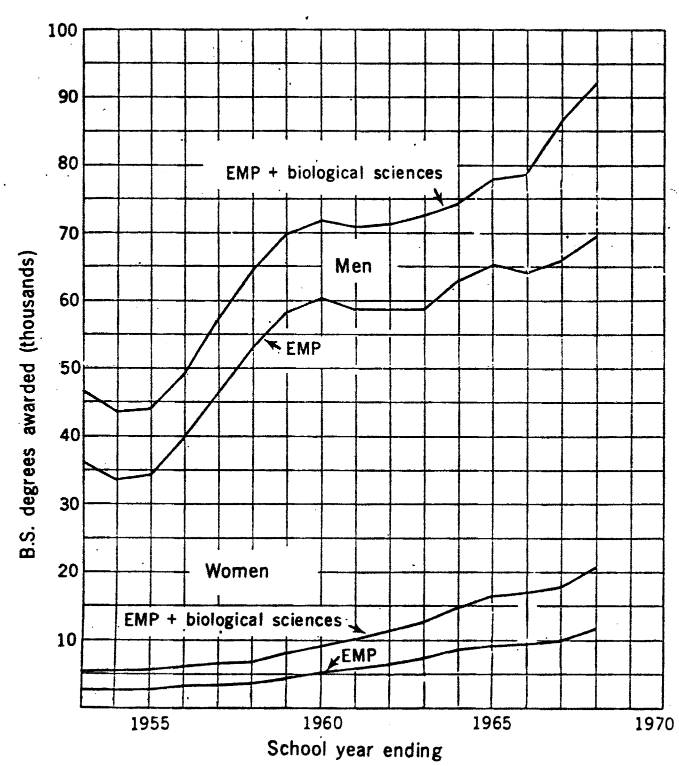
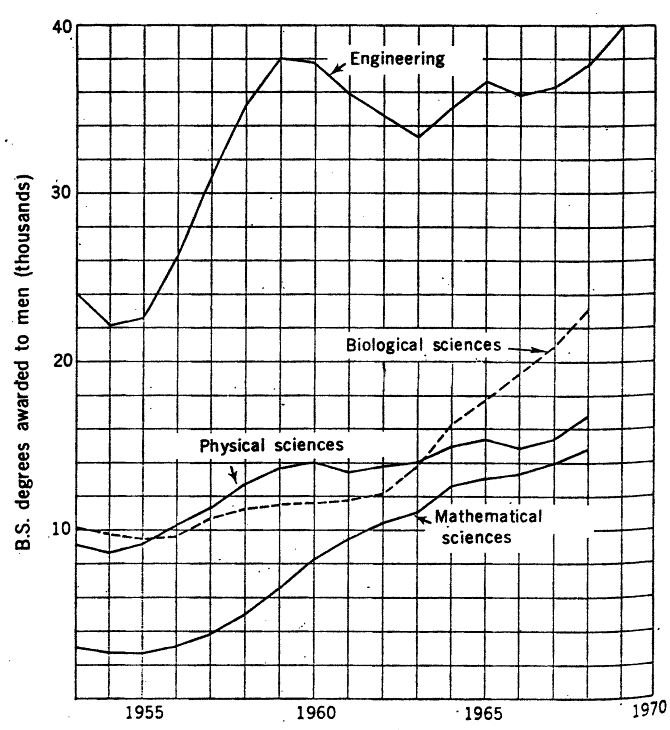


Fig. 1 (left). Men and women that are 22 years old (solid line), and men and women of college age (dashed line). [Census Bureau statistics]

Fig. 2 (below left). Baccalaureate degrees awarded in the engineering, mathematical, and physical sciences (EMP). Degrees awarded in all science and engineering fields, including the biological sciences (EMP + biological sciences). [U.S. Office of Education statistics]

Fig. 3 (below right). Baccalaureate degrees awarded to men in engineering and in major areas of science. [U.S. Office of Education statistics]





degrees awarded 6 years earlier in the same field is plotted in Fig. 13. These latter curves indicate the approximate percentage of recipients of the B.S. who successfully completed work for the Ph.D. (*3*). The data in Figs. 12 and 13 apply only to men; the number of women who carry their studies to the doctoral level in science and engineering is so small as to be statistically unimportant.

The growth rates of Ph.D.'s, as shown by the curves in Fig. 12, are all remarkably high. Table 2 shows that, over the period from 1960 to 1968, average annual increases in excess of 10 percent were typical; in engineering, these increases reached 17 percent.

Table 1. Rate of increase of M.S. degrees held by men. [U.S. Office of Education statistics]

Field	M.S. output		Average annual increase (%)
	1960	1968	
Engineering	7,159	15,152	10
Physical sciences	3,060	4,873	6
Physics	1,038	1,993	8
Chemistry	1,025	1,579	5.5
Mathematical sciences	1,428	4,202	14
Engineering, mathematical, and physical sciences	11,647	24,227	9.5
Biological sciences	1,668	3,963	11

Shortage or Surplus?

The total supply of scientists and engineers with the B.S., as projected in Fig. 8, seems to be adequate for meeting the nation's minimum needs, provided that these individuals are appropriately distributed among different fields. The future supply projected in Fig. 8 is a constant percentage of 22-year-old males, but a decreasing fraction of male college graduates.

However, if the nation is to have enough scientists and engineers of good quality to meet its basic needs, then a greater proportion of those students motivated to follow professional careers in science and engineering must continue their formal studies to the master's level. A 4-year program of study does not enable capable individuals to make full use of their potential in the more challenging and pressing scientific and engineering activities of our society. Equally important is the fact that 4 years of training do not provide an adequate basis for mastering developments in science and technology as they occur.

Changing Needs for Ph.D.'s

After many years during which Ph.D.'s appeared to be in short supply, people with new Ph.D.'s in certain areas are having difficulty in locating satisfactory jobs. The problem is not one of unemployment, since people with Ph.D.'s can always compete successfully for jobs normally filled by M.S. and B.S. graduates (*4*). Rather, the problem lies in the inability to achieve their job expectations, after having been led by teachers and advisers to believe that investing time and money in the Ph.D. would be the key to an exciting and attractive career. The disillusionment is greatest for those students who studied at the most prestigious schools, because their expectations were the highest.

What has been happening can be understood with the aid of Table 3, which shows the activities of Ph.D. scientists and engineers in the labor force in 1968. Of the 48,700 physical science Ph.D.'s in this census, 46 percent were employed by universities, while 41 percent were engaged in research and development (R & D) outside a university. Thus, nearly all of these individuals were engaged in teaching, R & D, or both. The last column of Table 3 shows that the Ph.D.'s produced in 1968 increased the number of EMP Ph.D.'s in the labor force by 9.7 percent (not including attrition by death, retirement, and so on).

Table 2. Rate of growth of Ph.D.'s. [U.S. Office of Education statistics].

Field	Ph.D. output		Average annual increase (%)
	1960	1968	
Engineering	783	2,921	17
Physical sciences	1,776	3,405	8.5
Physics	477	1,234	12
Chemistry	1,000	1,584	6
Mathematical sciences	285	895	15
Engineering, mathematical, and physical sciences	2,844	7,221	12
Biological sciences	1,086	2,347	10

During most of the 1960's, undergraduate enrollments in science and engineering were increasing rapidly (Fig. 8). Government-supported academic research and graduate enrollments were rapidly growing, as were government expenditures for defense and space work. As a consequence, there was a steadily expanding demand for new Ph.D.'s, and the growing number of Ph.D.'s produced each year (Fig. 12) was readily absorbed until the 1969–70 academic year.

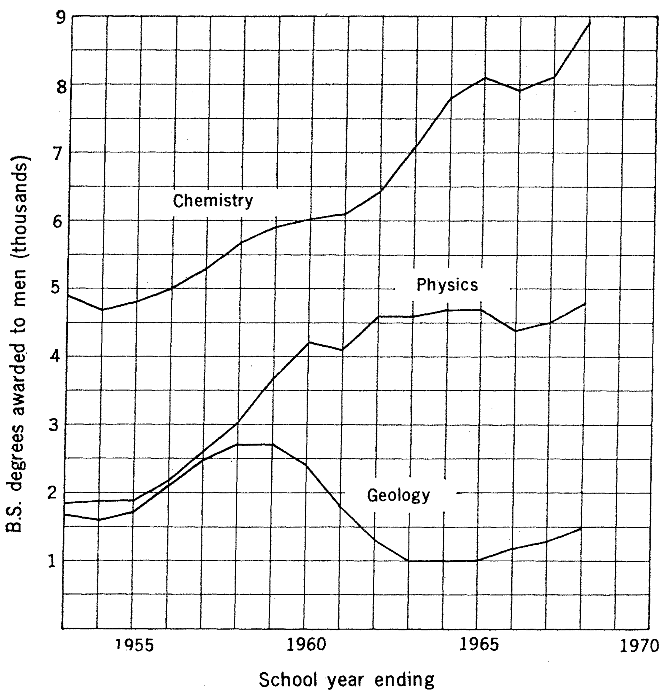
In 1969–70, things suddenly became different. First, the number of openings for young Ph.D.'s at universities suddenly and sharply dropped. This was partly because, beginning in 1969–70, the number of students studying science and engineering abruptly leveled off (Figs. 1 and 8). Concurrently, government funds for academic research leveled off, so that research and associated graduate activities in universities stopped expanding; in some cases, they decreased. All institutions of higher education have financial problems; as a result, they are running increasingly tighter financial operations.

Second, government expenditures on industrial R & D for defense and space, after having risen steadily during most of the 1960's, leveled off in the past 2 years. As a result, few new scientists and engineers with Ph.D.'s are being employed in these areas. Moreover, employment in defense industries is also suffering serious dislocations as some of the large programs are phased out and, occasionally, replaced by new programs at other companies.

Although some of the present conditions may not be normal because of such factors as Vietnam and anti-inflation efforts, there is no prospect of the pre-1969 employment situation for Ph.D.'s returning at any time in the foreseeable future (*5*). The number of undergraduate students in science and engineering shows no prospect of increasing rapidly, as it did in 1955 to 1969; rather, it can be expected to level off and then decline (Fig. 8). About the best that can be hoped for is that research funds will increase in proportion to increases in the gross national product; they will probably not regain the annual rate of 15 percent that obtained from 1960 to 1968.

Third, government funding for missiles and other technologically complex defense hardware, as well as space, can be expected to drop off as funds are diverted to pressing social needs. While there is much talk about the need for science and technology in solving social problems such as housing, pollution, inner-city decay, and so on, such talk has not yet produced very much in the way of dollars for academic or industrial research in science and engineering.

This does not mean that the need for individuals who are highly trained in science and engineering will decrease in the future. Rather, the present difficulties revolve around the fact that the primary markets for new Ph.D.'s are no longer academic institutions and basic research. Instead, new Ph.D.'s are employed by industry for applied



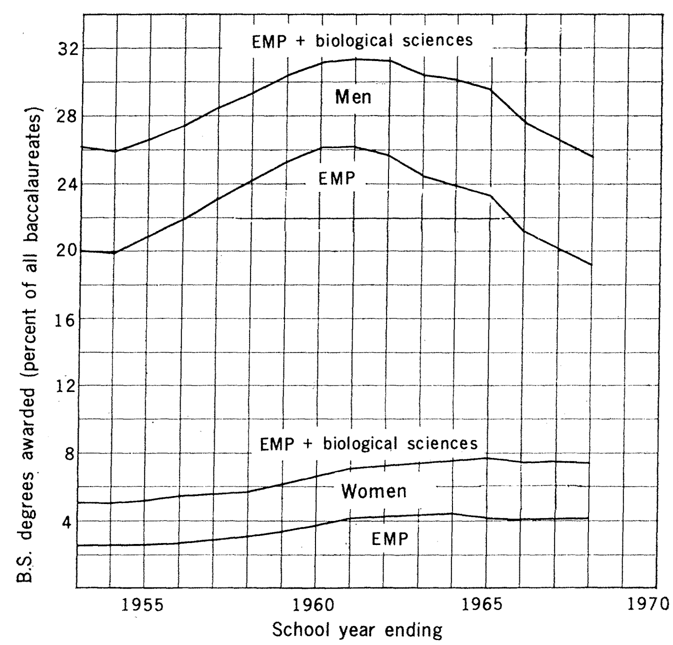
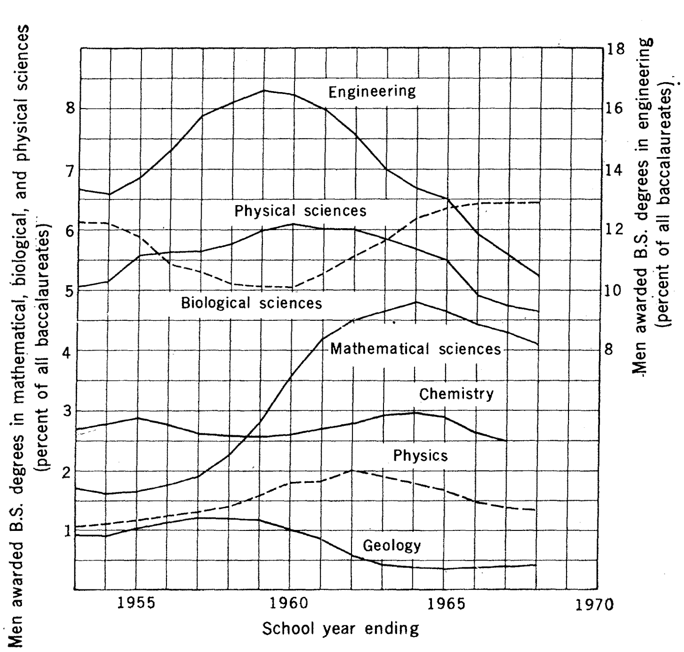


Fig. 4 (left). Baccalaureate degrees awarded to men in physics, chemistry, and geology [U.S. Office of Education statistics]

Fig. 5 (right). Baccalaureate degrees awarded in the engineering, mathematical, and physical sciences (EMP), and in EMP plus biological sciences, as a percentage of baccalaureate degrees awarded in all fields of study. [Derived from U.S. Office of Education data]



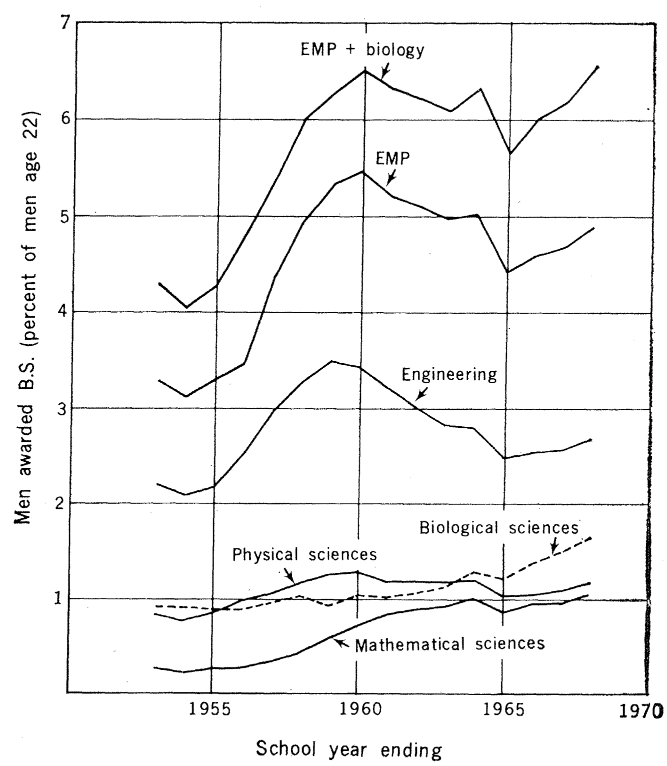
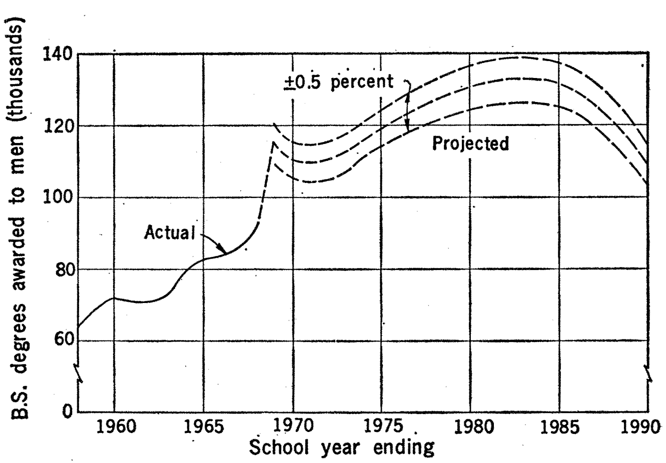


Fig. 6 (left). Baccalaureate degrees awarded to men in selected fields, as a percentage of all baccalaurete degrees awarded to men. [Derived from U.S. Office of Education data] Fig. 7 (right). Percentage of men 22 years old who received baccalaureate degrees in various areas of science and engineering (EMP denotes the engineering, mathematical, and physical sciences). [U.S. Office of Education and Census Bureau data] work that is less related to defense and space. Meanwhile, the orientation of people receiving the Ph.D. has not changed to reflect the new situation.

The typical holder of a Ph.D. in science, and, to some extent, in engineering as well, has been trained for a career that emphasizes research, particularly basic research conducted in an academic environment. That is, faculty members have tended to produce Ph.D.'s in their own image, with only a minimum of thought as to the needs of the industrial sector of the job market. Yet it is the industrial sector of the job market, particularly the sector that is not involved in defense or space, that must be depended upon to provide employment for the bulk of the new Ph.D.'s in the decade ahead.

In the past, about half of the Ph.D.'s in the EMP fields have found employment in industry (Table 3). However, while industry absorbed all the Ph.D.'s it was able to attract, it has never been entirely happy with the available prod-



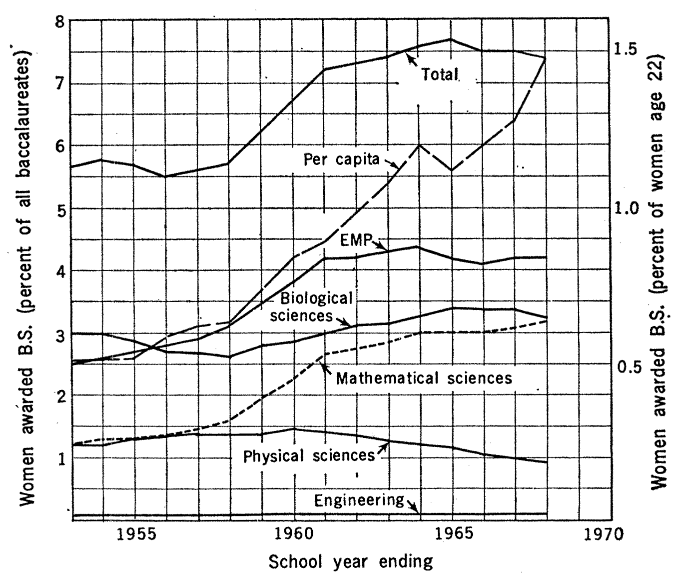
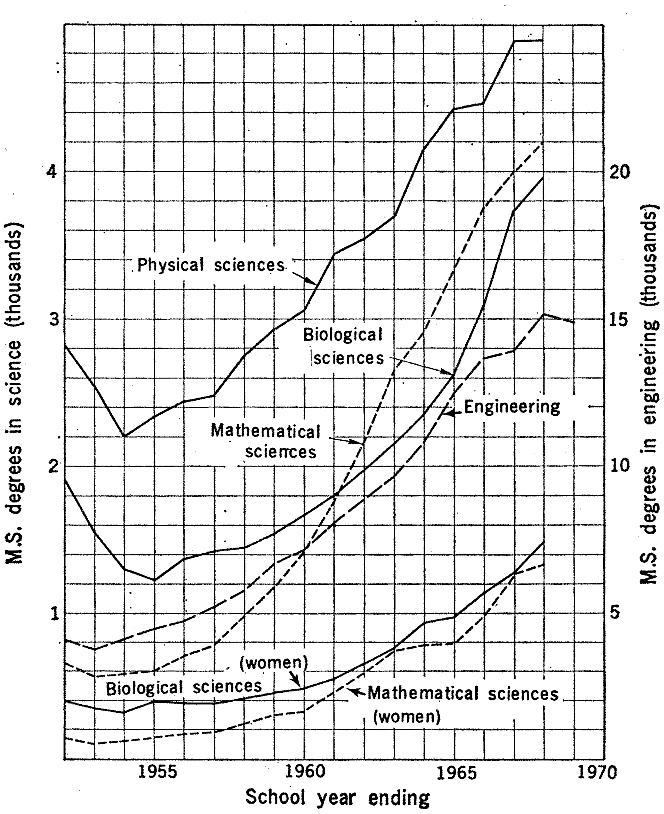


Fig. 8 (left). Number of baccalaureate degrees in science and engineering awarded to men, projected to 1990. Fig. 9 (right). Baccalaureate degrees awarded to women in selected fields (i) as a percentage of all baccalaureate degrees awarded to women (solid lines); and (ii) as a percentage of women who are 22 years old (dashed line, scale on right) (EMP denotes the engineering, mathematical, and physical sciences). [Derived from U.S. Office of Education data]



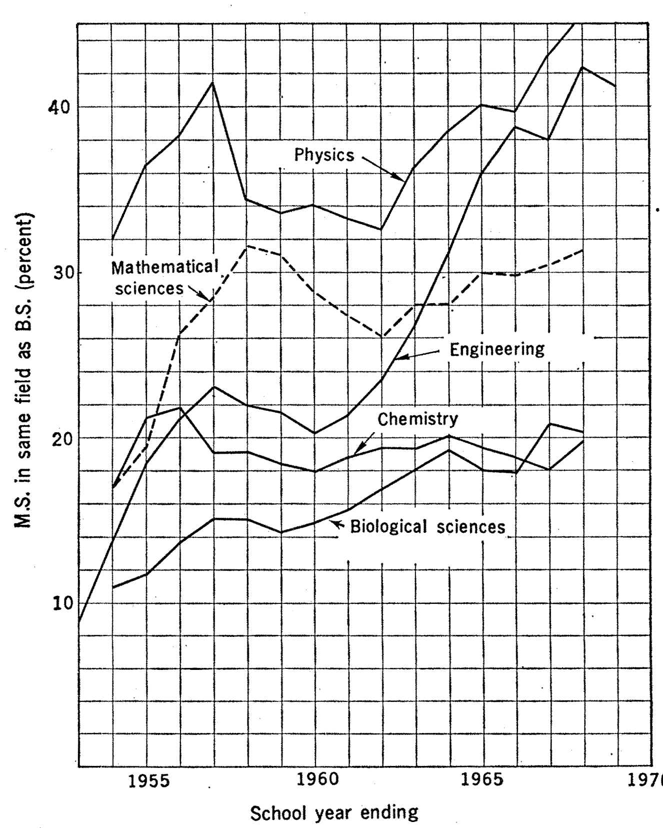


Fig. 10 (left). Master's degrees awarded in selected fields. The curves are for men, except where otherwise noted. [U.S. Office of Education statistics] Fig. 11 (right). Master's degrees awarded to men in selected fields, as a percentage of baccalaureate degrees awarded 2 years earlier in the same field. [Derived from U.S. Office of Education data]

Table 3. Activities of employed Ph.D.'s in 1968. [*Science and Engineering Doctorate Supply and Utilization 1968–1980*, National Science Foundation NSF 69-37 (Government Printing Office, Washington, D.C., 1969)]

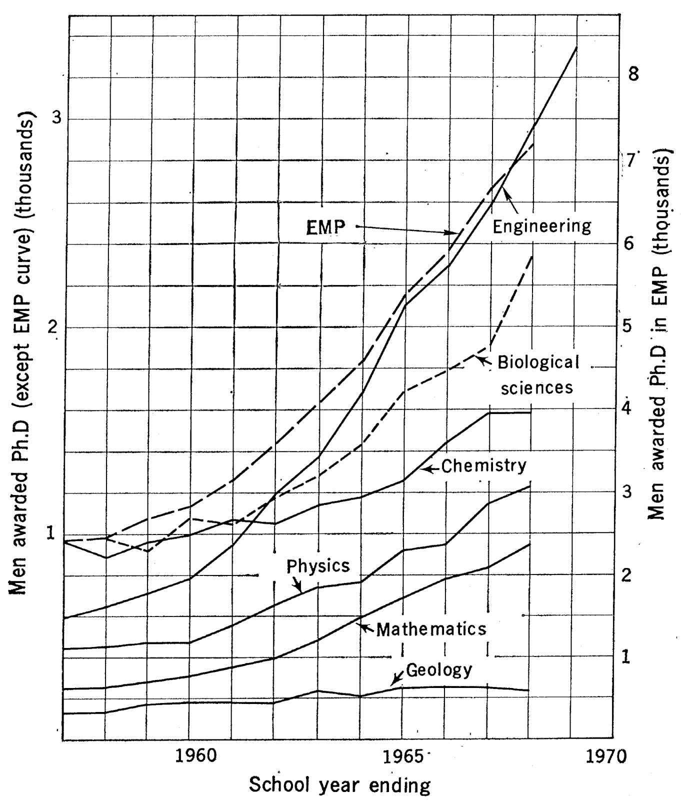
Field	University (%)	Nonuniversity		1968 Increment new Ph.D.'s (%)
		R & D (%)	Other (%)	
Engineering	45	37	18	14.6
Mathematics	82	7	11	11.4
Physical sciences	40	49	11	7.4
Engineering, mathematical, and physical sciences	46	41	13	9.7
Biological sciences	75	9	16	7.5

uct. Thus, at a meeting in September 1969, attended by 70 of the corporate associates of the American Institute of Physics, 93 percent of those present felt that "the training of physicists at the Ph.D. level is strong but narrow." All of them agreed with the statement: "graduate research supervisors instill attitudes in their students that result in low prestige for applied research among young physicists." Likewise, 79 percent agreed that "narrow training in highly specialized techniques . . . is not adequate for the rapidly changing frontiers of applied research." Finally, 93 percent agreed that "at present, physics professors recommend research in industry only to their poorer students; [however] the importance of some practical problems merits the best efforts" (*6*).

The exact situation varies from field to field, from subfield to subfield, and from one thesis supervisor to another. However, the fact remains that, even in engineering, which is generally more closely tied to the industrial world than are the science fields, a not insignificant fraction of the Ph.D.'s have characteristics similar to those of the physicists mentioned above.

Industry's extensive need for highly trained individuals is not now being met. Industry requires broadly trained, creative individuals who are flexible in their outlook, are capable of working in interdisciplinary teams, and are prepared to work on problems that need to be solved rather than on problems that are invented on the campus. The situation is well stated by the National Science Board as follows (*7*):

> There is need for a basic reexamination of the assumption underlying doctoral training in the physical sciences. The present doctorate was designed primarily as training for an academic career . . . and is based on the assumption that there should be no difference in the training of those heading for a university teaching or research career and of those aiming primarily at . . . industrial research.
>
> The problem may not be so much one of the content of the educational experience, as it is of the attitudes and values communicated by the graduate school. . . . There is increasing belief that a somewhat different type of training, equivalent in intellectual stature but aimed more suitably for nonresearch careers, should be available. Such training would still involve basic research experience, but possibly with greater breadth and variety and less specialization than the present degree. In the light of evolving industrial needs and changing social priorities, a more nearly fixed time period, less sharp specialization, and less emphasis on an original discrete contribution to knowledge should all be considered as possibilities in any review of the doctoral program. Consideration should be given to



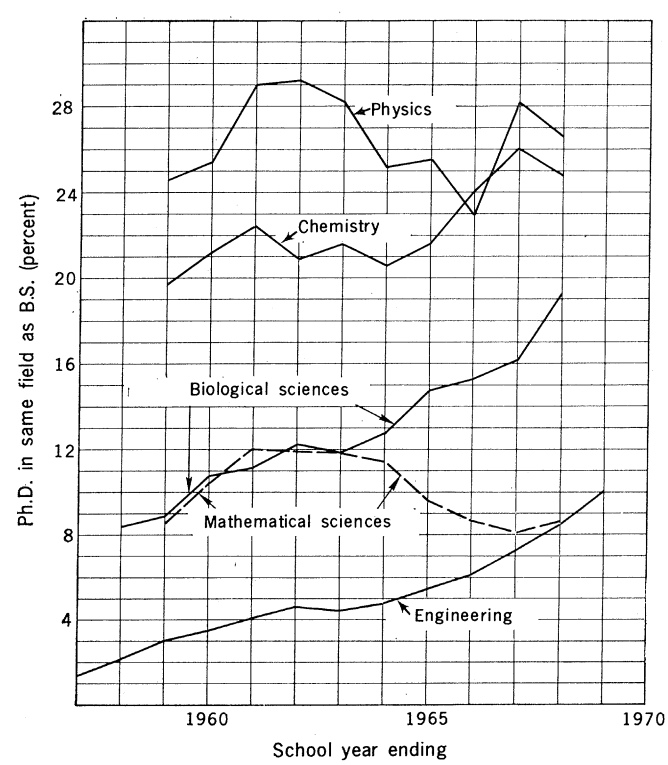


Fig. 12 (left). Doctorates awarded to men in selected fields (EMP denotes the engineering, mathematical, and physical sciences). [U.S. Office of Education statistics] Fig. 13 (right). Doctora tes awarded to men in selected fields, as a percentage of baccalaureate degrees awarded 6 years earlier in the same field. [Derived from U.S. Office of Education data] providing the student with a wider diversity of opportunities as he pursues his education. . . . Deep specialization in an original research contribution might well be reserved for post-doctoral experience.

The Ph.D. in the Future

It is clear that the production of Ph.D.'s in science and engineering cannot continue to expand in the 1970's as it did in the 1960's. In fact, the great consumers of Ph.D.'s in the 1960's, namely academic institutions and defense and space activities, will require substantially fewer new Ph.D.'s during the 1970's. While industrially funded research will continue to grow at perhaps twice the rate of increase of the gross national product, this is not enough to take up the slack. Accordingly, if the magnificent educational establishment that now exists in this country for producing highly trained scientists and engineers is not to wither away, new outlets must be found for its product. This means searching out new needs and hitherto neglected opportunities, and then developing the manpower markets thus defined.

This situation is quite different from that of the past, when professors typically trained young people along the lines of their own interests and had no trouble placing their protégés in satisfying positions. As the National Science Board says, the situation calls for reexamination and reorientation of both the content of and attitudes toward the Ph.D. degree. This will be agonizing and unsettling. The redeeming feature is that out of the stress and strain and pain and difficulties will come new ideas and new directions. This is not the time to complain about our present difficulties; it is, rather, the time to seek out new opportunities and to make the most of them.

References and Notes

1. The term "science" is used throughout to denote the natural sciences (that is, physical, mathematical, and biological); social and behavioral sciences are not included.
2. This retreat from science and technology exists not only among college students in general, but, even more disturbing, among the very brightest college students. This is shown by changes in the distribution of career choices of male finalists in the National Merit Scholarship Program over the decade 1957 to 1967, reported by D. J. Watley and R. G. Nichols [*Eng. Educ.* **59**, 975 (1969)].
3. The data in Fig. 13 need to be corrected for foreign students who received their undergraduate training abroad. The information required to make this adjustment is not available, but it is estimated that something like 10 to 20 percent of doctoral degrees fall into this category, with the fraction varying from field to field. Also, these curves are not corrected for students who received their Ph.D. in a field different from that in which they received their B.S. degree.
4. This is verified by a study of the employment status in early 1970 of 1967–68 and 1968–69 recipients of Ph.D.'s in the natural and social sciences and engineering [Office of Scientific Personnel, National Research Council, *Science* **168**, 930 (1970)].
5. A stimulating discussion of this matter is given by J. P. Martino [*ibid.* **165**, 769 (1969)]. Martino points out that, when the rate of growth of science appreciably exceeds that of society as a whole, the growth rate of science must soon level off. On the arbitrary assumption that this leveling off became effective in 1968, Martino shows that "U.S. universities will find that they are required to turn out a much smaller number of graduates. . . . The science staffs of U.S. universities are already larger (as of 1968) than the staffs which would be required in 1975. . . ." This gloomy day will unquestionably be pushed further into the future by broadening the scope of activity of those possessing scientific training; nevertheless, this day of ultimate reckoning hangs like a threatening sword over the head of the scientific establishment.
6. A. Strassenburg, *Phys. Today* **23**, 23 (1970).
7. *The Physical Sciences*, report of the National Science Board (Government Printing Office, Washington, D.C., 1970).

NEWS AND COMMENT

VEE Vaccine: Fortuitous Spin-off from BW Research

For more than a month now, the first recorded outbreak in North America of Venezuelan equine encephalomyelitis (VEE) has raged northward from the Mexican border, killing hundreds of horses and felling scores of humans with a milder but still severe flu-like illness.

As the virus spread outward from southern Texas last week, state and federal health authorities struggled to create a wide "barrier" of vaccinated horses from Florida to California in order to contain the disease along the nation's southern margin, if not in Texas alone. Flying in support of this campaign, Air Force planes, skimming low over the coastal grasslands of Texas and Louisiana, sprayed malathion to kill the mosquitos and biting flies that carry VEE virus. Airlines took the extreme precaution of discreetly fumigating passenger planes departing from four south Texas cities to prevent infected insects from riding out beyond the epidemic area.

These nonpersistent insecticides, however, are of secondary importance in the battle against VEE. Their killing power lasts no more than a week, and mosquitos multiply very quickly. Therefore, health authorities are pinning their hopes for control on keen surveillance of the disease—and on the vaccination campaign that is supposed to lay a firebreak of immunity ahead of the virus' advancing front. "This is how we'll succeed," says Clark W. Heath, Jr., an epidemiologist at the Public Health Service's Center for Disease Control (CDC) in Atlanta. "If we succeed at all," he adds.

If the combined forces of the Public Health Service and the Agriculture Department do succeed in curbing or even halting the VEE outbreak, much of the credit will be due a pair of rather silent partners in the battle. The partners are the U.S. Army, which is furnishing the vaccine, and, ironically enough, the Army's program of biological warfare, which developed the vaccine.

"It's the only effective vaccine against VEE in the Western Hemisphere," an Army spokesman said. "It can be considered a beneficial result of biological warfare research."

Indeed, eight Latin American nations have benefited from the vaccine since the Army began making it available through the State Department in 1967. More than 2 million doses of the vaccine—designated TC–83—have since been shipped, with varying results, to Colombia, Honduras, Costa Rica, Panama, El Salvador, Nicaragua, Guatemala, and Mexico.

In the summer of 1969, for instance, U.S. and Guatemalan authorities used the vaccine to form a 30-mile-wide barrier of immune horses around a pocket of VEE infestation along that country's Pacific coastal plain. This Maginot strategy kept the disease at bay for nearly a year, until it somehow breached the barrier and flared up in Costa Rica last summer.

But the Army's involvement with