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Approaching Ceilings in the Supply of Scientific Manpower

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At the present time there are scientists and engineers among the nearly 4 million unemployed in this country, and yet a shortage of scientists and engineers is claimed. There are many college graduates who majored in science who are not permitted to teach science in our elementary schools because of a lack of education courses, and yet at the same time, those without science training try to teach science in our schools. How can unemployment and shortages exist at the same time? Perhaps we need some better national planning and a reasonable allocation of priorities for personnel, programs, and funds, to prevent distorted and unbalanced conditions. Distortions are often made in analysis and prediction of our educational attainments based on the average of the whole rather than on separation into reasonable component parts. Conant (*1*) has cited the danger of considering the high school and college dropout of the nation as a whole, because good areas tend to balance bad areas and the figures leave the impression that we are not doing too poorly when, in fact, many areas are in need of assistance.

In this study an endeavor is made to evaluate our potential supply by a separation of those portions of the population which, by reason of aptitude, sex, ability, or interest, tend to form our professionally oriented student group.

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Definitions of Science

Some broad definitions of "science and technology" include "social science" (economics, history, and sociology), whereas some limited definitions of science exclude mathematics or the biological sciences. The National Academy of Sciences and the U.S. Office of Education consider science and engineering to include mathematics, physical sciences, biological sciences, and engineering. In fact, the broad use of the word *science* should include the concept of "science and engineering" (*2*). The confusion of definitions is evident in many reports. A recent report on "Science and engineering manpower" (*3*) includes mathematics and omits the biological sciences, whereas the directive for the report (*4*) omitted mathematics and included the biological sciences. A recent tabulation of science degrees by the National Science Foundation (*5*) includes the social sciences. The National Research Council (*6*) includes the behavioral sciences, whereas the U.S. Office of Education does not include the behavioral sciences (*7–11*). Not all science is physical, nor are all scientists from the academic area.

Projected Growth

Data on the production of college graduates and on projected growth have been presented (Fig. 1) on a logarithmic scale so that uniform rate of growth will show as a linear rather than an exponential effect. In the 1800's and early 1900's, the age-22 population group in the United States was larger, by several orders of magnitude, than the annual number of college graduates, and changes in population had little effect on the number of graduates.

The rapid rise in the number of college graduates, as compared with a nearly static population of the college age (1920–60), has led to a nearly saturated condition. Fluctuations in population are now reflected in college enrollments and graduations, and the rate of expansion in numbers of college graduates is showing signs of leveling off and paralleling the population growth at what might be termed a ceiling of maximum utilization. Certain areas of our educational system are essentially at ceilings established by our population growth rate; this is certainly true in the number of elementary school graduates. The number of high school graduates is approaching this ceiling, with nearly 80 percent of the age group graduating from high school (*2*).

The data in Fig. 1 are an indication of the annual number of graduates. The annual number of first-time enrollments is nearly twice the number of graduates, hence, enrollment values are much nearer the potential saturation. Today (1962–63) (*8*) we admit to college about 43 percent of the age group; this 43 percent includes 52 percent of the men and 36 percent of the women of the age group.

With the admission to college of about 50 percent of the males from the age group, we must be approaching our ceiling of capability. In Europe, only 8 to 10 percent of the age group are offered the opportunity of a college education. It has been suggested that probably 20 percent of the age group is the maximum we should graduate from college at the present time. To graduate this percentage, as well as to handle those who take junior-college or 2-year technical courses, at least 40 percent of the college age group should be admitted to college. Others feel that almost anyone who really wants to can go to college and graduate if given sufficient time and assistance, and that we should admit many more, so as to "catch" the late-bloomers or dormant geniuses who are not aware of their hidden abilities. It is difficult, however, to conceive of a genius who does not know he is a genius. Many do not agree with such a philosophy of broad, "catch-all" education and feel that college education should be limited to those who know they should go to college and who can accept and maintain a reasonable standard of proficiency.

A compromise suggestion to those who wish the "open door" has been that perhaps we might admit 50 to 60 percent of the age group rather than the present 35 to 40 percent, and thus graduate about 25 percent of the age group rather than the present 18 percent. What the "open door" proponents may not realize is that these percentages refer to the age group as a whole and that, as far as the male constituents are concerned, we are already at these upper limits. In 1962 we admitted to college 601,000 men, or about 52 percent of the males of the college-entrance age group, and graduated 255,000, or about 24 percent of the males of the college-graduating age group. In other words, we have already met this expanded goal for the male group. True, we admitted only 38 per-

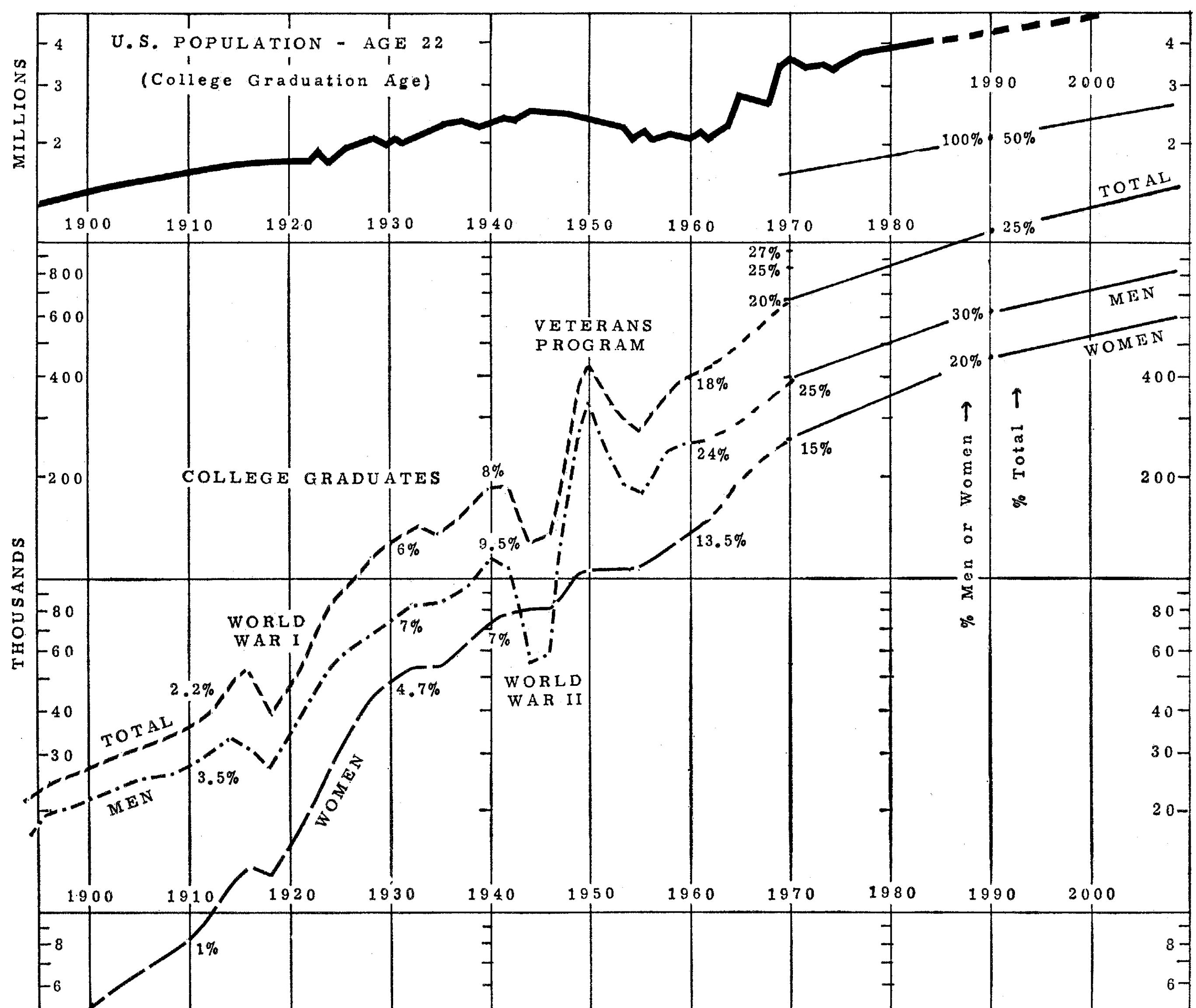

Fig. 1. College-age population and numbers of graduates. (Top curve) U.S. population of those annually reaching the age of 22 (*22*) (see Fig. 3 for more detailed population data). (Bottom curves) The number of bachelor-degree graduates per year in all subjects, and breakdown between numbers of men and women graduates (*7–11*). The percentages along the "total" curve pertain to the total age group (men and women); those along the other two curves pertain to the total number of men, or women, in the age group. The "25%" and "27%" above the "total" curve on the 1970 ordinate are proposed objectives of two recent projections (*3, 5*). The projected growths from 1970 to 2100 are based on the predicted population growth (*2*) and on the assumption that a ceiling of about 25 percent for bachelor-degree graduates will be reached by about 1990. The "100%–50%" line parallel to and below the population curve (top) for 1970 to 2100 represents the total number of men (or women) in the age group and is the 100-percent maximum against which the predicted ceilings of 30 percent for men or 20 percent for women should be compared.

cent of the women of the age group and graduated 13.5 percent. To effect a major increase in number in the group which provides 95 percent of the scientists and engineers (the male group) will require lowering standards so as to admit considerably more than 60 percent of the age group and to graduate more than 25 percent of the age group.

I have previously stressed (*2*) that, as we near the maximum utilization limits, our greatest effort should be turned toward improved quality, improved teaching methods, better utilization of our trained product, and a rational system of priority allocation of valuable personnel.

While the numbers of men and women in the population are practically equal and will remain so in the future, there are changes in the relative composition and character of our college and university student body which, in the long run, may influence the predictions of those who would make linear extrapolations from logarithmic data for the combined student population. It is noticeable that the proportion of women in our colleges is rising and that the major increases in college enrollments in recent years have been due to this factor. On the other hand, it is evident that the proportion of women who pursue professional careers in their fields is less than the proportion of men who do so, hence that the increase in numbers is not as effective in increasing the labor pool as one might expect. About 50 percent of the women who enroll in college will eventually graduate, while about 60 percent of the men who enroll will graduate.

Any proposal to raise the total number of science and engineering majors and graduates above the present proportion of the college-graduating age group (20 percent of the college graduates or 4 percent of the age group) must recognize that we must either develop a demand for women scientists and engineers (a problem which has not as yet been fully met or solved) or continue our present practice of utilizing mainly men (95 percent) in science and engineering and depend on increasing the number of graduates in the male group. Recent proposals (*3, 5*) have suggested increasing the total percentage of the college age group graduated from the present 18 percent to 25 or even 27 percent. This raising of the total percentage of graduates would mean, on the basis of present distribution, raising the percentage for males from the present 24 percent to about 35 percent of the males in the college age group. To graduate 35 percent (*12*) of the age group would essentially mean lowering standards, for this would require about 75 percent of the males in the age group, as high school graduates, as the raw material with which to start. This would be nearly all of the males in the present high school graduating group, hence, there could be no standards of admission other than a high school diploma. Our present college "mortality" is about 50 percent, and if we are to pass and graduate a larger proportion of the age group, then a still larger proportion must enter college, since the students who do not now go to college are largely those of lower ability, and the less able are the more likely to fail.

In a reverse sense, if we were to reduce the proportion of those graduating from college to 10 percent of the age group, and if these, as entering students, were carefully selected from the top 15 or 20 percent of the age group, there would be few, if any, failures, hence, a proportionally low mortality rate. Such a situation is to be found in some of the European and Soviet schools, as well as in some of our own selective-enrollment universities or colleges.

With the continued pressures that have existed for some years to increase the proportion of scientists and engineers, the maximum utilization of our resource material appears to have been effected, or the ceiling will have been reached when additional enticements and numbers of enrolled students fail to provide an additional proportion of professional candidates or majors in science and engineering. The leveling off of the percentage of the age group in science and engineering, in spite of continued expansion in nontechnical majors, should certainly be accepted as a sign that we are approaching the ceilings.

Women provide for some areas of science and technology a possible additional supply, but this will be limited by ability to maintain continuous employment, by adaptability, and by numbers. If we continue our present pattern of gradual expansion and assimilation of larger numbers of women in science, we would seem to be moving toward a reasonable expansion procedure and a solution to the problem, but it will take a long time to effect this.

Standards of Reference: The "1950" Standard

It appears that undue emphasis is often placed on the nation's educational accomplishment in the year 1950. That year is often cited as a standard or reference year. However, there are in fact two periods, 1941–1947 and 1948–1954, which are quite anomalous in our national educational history. Between 1941 and 1947, during World War II, a high proportion of men of college age were in the armed services or in defense work, and this is the only time in our educational history when women outnumbered men in our college enrollments and graduations. Between 1948 and 1954, almost simultaneously with the Korean war, we had a special veteran's benefit program to provide educational opportunities to the large number of veterans who missed out on college in the early 1940's. It is both inaccurate and unrealistic to use either the 1944 (low) or the 1950 (high) data on education, enrollments, or graduates as standards or normal reference points (see Fig. 2). In 1944, only 44 percent of the

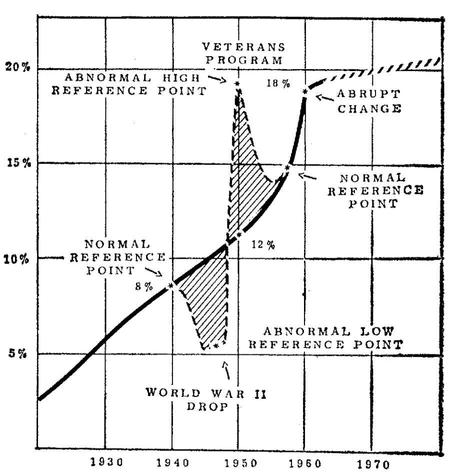

Fig. 2. Percentage of the age-22 group who become college graduates, showing the effect of veterans program on age level at graduation. The dashed curve is based on the actual number of graduates each year between 1940 and 1956 (it is assumed that all were age 22 in the year of graduation). The solid curve between 1940 and 1956 was obtained by reassigning dates of graduation for delayed veteran graduates to the year in which they would have been age 22. Shaded areas indicate either deficiency (1940–48) or excess (1948–56); the two areas are essentially in balance (*7–11, 13*). The abrupt change at "18%" (1960) is due to the simultaneous saturation of supply and a change from a nearly constant population to an accelerated population growth. Note the 50-percent increase from 12 percent in 1950 to 18 percent in 1960.

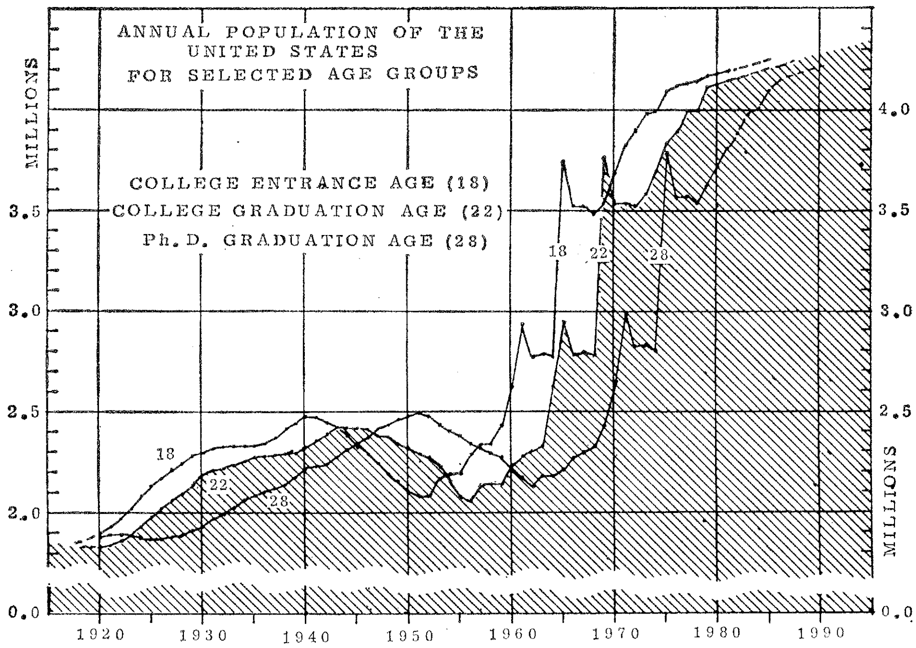

Fig. 3. The population of the United States by selected age groups. (Curve at left) College entrance—age 18; (center shaded curve) college graduation—age 22; (curve at right) Ph.D. graduation—age 28. Data are from U.S. Census Bureau releases (*22*). [The age-22 population is nearly constant (about 2.3 million ± 10 percent) from 1930 to 1965. There is a 5-percent decline (120,000) in the age-22 population from 1950 to 1960. Some prefer to use the age-24 population as the college-graduation group. The decline in this group can be estimated by interpolation between the age-22 and the age-28 data and appears to be more than a 10-percent drop between 1950 and 1960. In a discussion on the supply of college graduates (*3, 4*), this decline in population between 1950 and 1960 has been termed a "substantial increase in our population."]

college graduates were men and 56 percent were women. In 1950, however, 76 percent of the graduates were men and only 24 percent were women (see Fig. 1).

The average distribution of men and women among our college graduates in the periods prior to and following the abnormal periods was about 60 percent men and 40 percent women. Unfortunately, we find publications from the President's Science Advisory Committee (*3, 4*), from the U.S. Office of Education (*7–11*), from the National Science Foundation (*5, 6*), and in other studies, in which 1950 is repeatedly used as a reference or standard year and the high, anomalous number of graduations produced by the combination of veterans and regular students is held up as a normal or even superior standard to aim for, without any hint or indication that this was an abnormal year or that there was anything anomalous about the data.

Not only are the ages and the proportion of men and women, as well as the total numbers, out of line in the 1950 data as compared with normal trends but, for the male component, the proportion of men in science and engineering is also abnormally high. Many of the veterans had some indoctrination in the armed services in science and engineering, often with special training courses which many schools accepted as partial credit toward fulfillment of degree requirements in science and engineering majors. During the height of the veteran's benefit program (1948 to 1953), the percentage of engineering degrees awarded to men rose to a high point of 17.1 percent, whereas the average from 1955 to 1961 was only 13.5 percent.

One must not interpret the sharp peak in 1950 (Fig. 2, shaded area above the solid curve) as the full measure of the effects of delayed education of veterans or individuals who did industrial or special defense work during the war-time emergency, because, in fact, in 1950 and 1951 we were engaged in the Korean conflict and many of those of normal college age were in the armed services. The veteran's benefit program was thus extended to 1956, and the 1950–51 expansion was less than it would otherwise have been. The World War II veterans in college essentially eliminated any deficiency resulting from the Korean conflict; because there were three times as many World War II trainees as Korean, the combined effect is a lowering of the total in 1950 and 1951 and a broadening of the veteran effect up to 1955.

To determine a proper value for 1950, it is necessary to reassign the 1941–57 graduates to what would have been their proper age groups, so that the values for any one year represent the number of people who would have been 22 in that year and who are now college graduates (*13*). It is true that some were delayed by war service, but essentially all of these who will graduate have now completed their academic studies. This method of recording the college graduates as a percentage of their "age-22" group permits a direct estimate of the expansion of our educational program and a measure of the expected ultimate retirement rate. This calculation has produced the heavy black line in Fig. 2 between 1940 and 1957. This should be the reference line for estimating net growth, rather than the fluctuating dashed line over this same period. The dashed line indicates deficiencies and excesses of a temporary nature.

It is interesting to note, from the solid black line in Fig. 2, that there was a 50-percent increase from 1950 to 1960, 12 percent of the age group graduating in 1950 and 18 percent of the age group graduating in 1960. This 50-percent growth has been referred to by some as a decline in production (*3, 4*), even though a major backlog of veterans was also handled by our universities and colleges in the same period. Rather than being criticized for a nonexistent "reduction," our educators should be complimented for a 50-percent expansion in face of a very difficult situation which has, in part, been produced by the same groups which criticize the universities for failure to produce. This increase in the number of scientists and engineers was effected in spite of a 10-percent drop in the population of the college age group in this period. The opposite statement has been made—that the production of scientists had gone down and the population had gone up—and this situation has been used as the basis for special studies and the claim that there was a crisis in education (*3, 4*).

There is a crisis, but it is one of approach to a limited supply ceiling and the need for better and more efficient education rather than a need to produce more trained individuals. Production of more, after the ceiling has been reached in the supply of qualified candidates, merely means lowering the standards to create more poor scientists and engineers.

The dashed line in Fig. 2 represents the percentage of the age group graduating each year, calculated on the assumption that all graduates were of the age-22 group. We know this assumption to be in error; hence it is logical to reassign these graduates to their proper age group. The data published by the Office of Education and the Veterans Administration Bureau (*7–11, 13*) are not complete enough to permit separation of these reassigned veterans into groups according to majors, but there is every reason to believe that their distribution would follow closely the normal distribution, in which about 20 percent of the graduates are in science and engineering. The separate data on engineers, chemists, and physicists which we do have indicate that a little more than 20 percent of the graduates were science and engineering majors during this period.

In the last 6 years we have been essentially free from the effects of veterans' programs. Up until 1958 there was a continuation of the accelerated expansion in the proportion of the college age group graduating from college, but since that time there has been a gradual leveling off. There are two major explanations for this change: one is the approach to the maximum utilization of available students who can properly qualify for college education and the other is the approach of the population bulge, which will be effective from 1963 to 1970 (Fig. 3). An examination of the separate figures for men and women graduates between 1955 and 1962 (Fig. 1) shows that the number of men graduates has leveled off in recent years and that the increase in the total number of graduates has been due mainly to a continued increase in the number of women graduates. This latter fact can be of little comfort to the promoters of increased numbers of scientists and engineers relative to our total expansion when it is realized that 95 percent of our scientists and engineers come from the male portion of the population. The future trend seems to be an obvious leveling off or a reduction in the rate of expansion (Figs. 1 and 2). With the increase in population of the college age group there will be a corresponding increase in the number of graduates, even though the percentage of the age group graduating (Fig. 2) may stabilize near 20 percent in the early 1970's and may not approach a possible 25 percent until about 1990 (Fig. 1). It will probably tax the abilities of our universities and their faculties just to keep up, in the immediate future, with the expanding population and to maintain the present level of graduation of 18 to 20 percent of the college age group. Optimistic projections have contemplated graduation of 25 or even 27 percent of the age group by 1970 (*3, 5*) (Fig. 4), but the conservative view is supported by indications of saturation in courses of a professional character, such as the sciences and engineering, at our present 18-percent level.

The bulge in population which is about to take place in our colleges definitely calls for a halt in the expansion in the percentage of college age students admitted and graduated. There must be higher entrance requirements and better selection of students. Future leadership in science and technology is not to be based on numbers but, rather, on improved quality of the graduate. This will require better teaching of only those who are qualified to receive instruction.

Limitations in the Supply of Chemists

As previously noted, the combination of conflicting statistics, such as those for delayed veteran graduations and regular student graduations, leads to confused information with regard to educational growth (Fig. 2). Somewhat similarly, the combination of science-major data covering several different sciences and various types of professional and nonprofessional degrees makes it difficult to observe significant changes. The study of trends in a single important science, such as chemistry, for which many data are available, permits analysis of the data

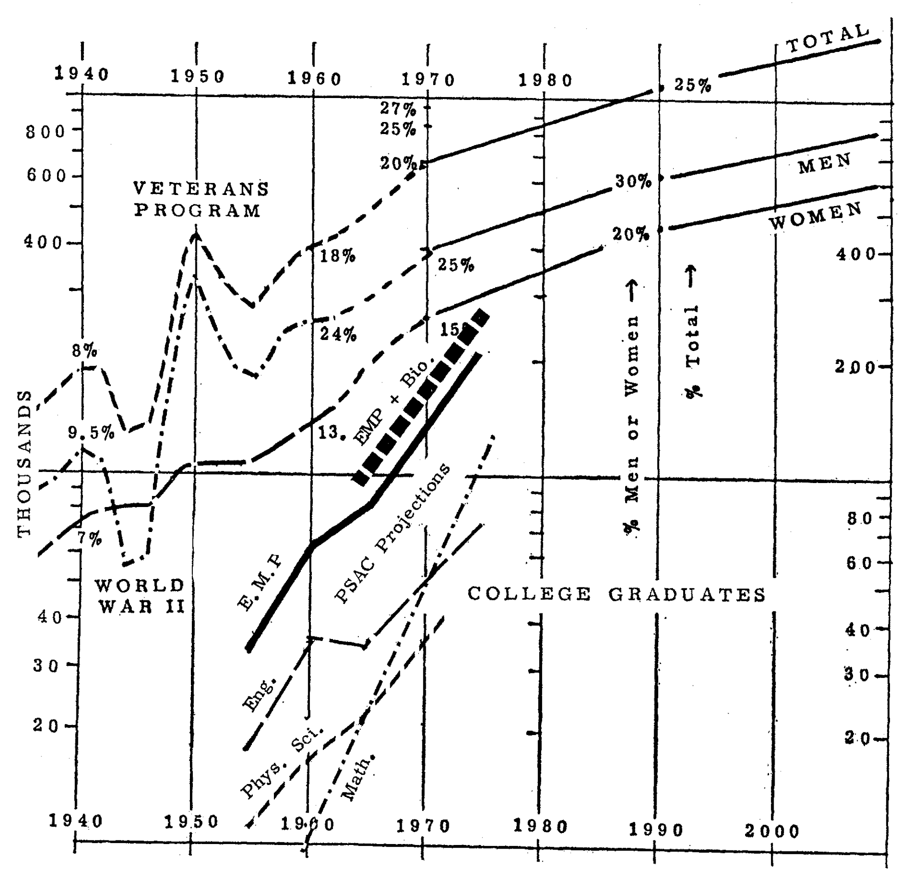

Fig. 4. Projected growth in engineering, mathematics, and physical sciences, as proposed by the President's Science Advisory Committee report (*3*). The projected 1970 rates, if extended to 1975 and broadened to include a proportional expected increase in the biological sciences, would require about 275,000 graduates (nearly two-thirds of the expected male graduates). The present distribution is about one-third of the male graduates in science and engineering.

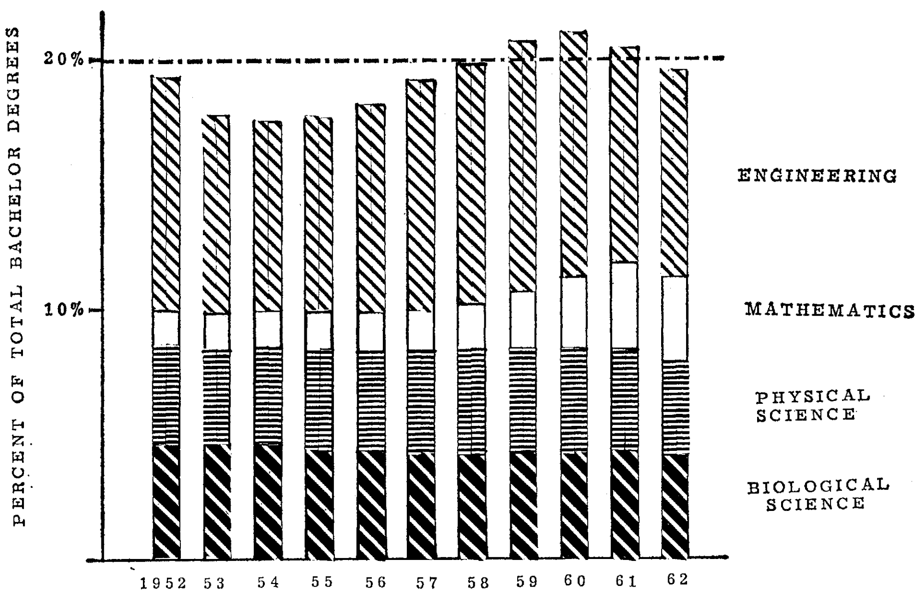

Fig. 5. Percentages of degrees in science and engineering relative to the total number of bachelor's degrees. The actual number of degrees conferred can be calculated from these percentages, the population of the age group (Fig. 3), and the percentage of the age group graduating (Fig. 2). It should be noted that mathematics is the only area of science and engineering in which there has been an appreciable increase in the last 4 years (*7–11*).

and detection of significant signs of possible saturation.

For some time there has been a failure to expand, even a slight recession in, the annual production of engineers (*10*). Last year there was a decline in the number of engineers for the third successive year, with a 5-percent drop over the previous year. Stabilization of growth, or even minor decline, has not been as noticeable in the sciences, because of the combination of statistical values from various curricula and sources, which tend to cancel out and leave an erroneous impression. Figure 5, however, does show that, in the percentage of total degrees, there is a leveling off, and were it not for the one positive area of mathematics, the last 5 years would indicate a slight but steady decline in all sciences. The physical sciences showed, in 1961, a 3.5-percent decline over 1960, and there is an estimated further annual decline of about 3 percent in 1962. The decline in the percent of the student body majoring in the physical sciences is in part due to a marked decline in the geological or earth science majors, but is also due in part to the increase in enrollment in the nontechnical areas of our universities by students who are not inclined toward the sciences.

Chemistry, as one of the older scientific specialities, has had a higher level of efficient production of degrees than have many of the smaller or newer scientific areas. For some time, about one-fourth of all the Ph.D.'s in science and one-half of all the Ph.D.'s in the physical sciences have been in chemistry. Chemistry also produces about half of all the bachelor's degrees in the physical sciences. By reason of these large numbers of degrees, there has been a better opportunity to establish curricula and degree procedures. The American Chemical Society (the world's largest scientific society, with over 90,000 members) has, through its committee on professional training, established general levels of attainment and curricula for the professional chemist. The separate information studies, by the society and others (*14, 15*), provide, in addition to the information from the Office of Education, essential data for differentiating between professional and background training programs in chemistry.

For some time the society has recognized that a minimum degree in chemistry from an academically accredited and recognized institution did not, in itself, guarantee professional training in chemistry to a point where one might engage in the profession or call himself a professional chemist. To some extent our engineering societies, too, have felt the need for standards of certification that certain broad requirements in engineering training have been met. Similar certifications exist in medicine, law, pharmacy, education, and other areas. In chemistry, however, there is no requirement that an individual or school conform to the curricula suggested by the ACS and the society only examines and approves a program at the invitation of the institution. One can be reasonably certain, however, that a student who completes the courses which satisfy the ACS certification requirements is headed toward professional work in chemistry, since the requirements are considerably higher than the minimum requirements for a degree in chemistry. These ACS-certified graduates may be said to have met requirements for a professional degree in chemistry. This professional status is well established by the fact that 33 percent of the ACS-certified graduates go on to obtain Ph.D. degrees (*14*).

There is a surprising "discrepancy" between the number of science graduates indicated in the Office of Education data (*7–11*) and the number of graduates who go on to be professional scientists (*16, 17*). Some 70 percent of the science graduates leave science for other professions. For many, a B.S. in science is merely a termination course. Perhaps we should feel happy that so many in business, politics, education, and other cultural areas in our community have a scientific background. In studying profession versus background major, it has been considered that medicine, dentistry, public school teaching, nursing, and similar areas are not professional science, even though a preprofessional course such as chemistry may be taken as a major for the B.S. In comparison, one might note that, in engineering, some 85 percent of the graduates practice professionally and only 15 percent drop out for other activities.

This difference in the continuation and dropout rates in science and engineering explains why, although the number of annual graduates in science and engineering are about equal (about 40,000 each in 1962), we have, in the labor force, about a million engineers and only 250,000 scientists.

A great deal of the calculation and planning for the future of science (*2, 3, 5, 14*) has been based on an extrapolation of the total number of graduates [Office of Education figures (*7*)], regardless of whether the major led to a professional degree or was merely a background or minimum requirement major. The fact that some 70 percent of the bachelor's degrees in science do not lead to professional careers in science makes it difficult to predict from the known production of bachelor's degrees the probable number of future professional scientists.

In chemistry, however, and especially in schools approved under the ACS program, it is usually possible to differentiate between students who take a chemistry major for a professional career as a chemist and students who take a chemistry major as background or preprofessional training for a professional career in some field other than chemistry (*16*). The ACS listing of approved schools and the ACS-certified-graduate program have been in operation for over 20 years, and the 300 ACS-approved schools include essentially all of those granting Ph.D. degrees in chemistry (110 schools). The ACS-certified graduates provide some three-fourths of the raw material or candidates for our Ph.D. degrees in chemistry. There are some 1400 degree-granting institutions, but only 830 give bachelor degrees in chemistry. With 300 of these schools approved by the ACS, there would appear to be some 530 schools giving bachelor degrees in chemistry which have not as yet been approved. An institution is considered by the society only if it seeks approval, and there are some institutions of high quality which, for good and sufficient reasons as they see it, have decided not to seek, or have even decided to withdraw from, approved status. Other institutions have sought approval but for various reasons, such as heavy teaching loads, lack of certain courses, limited library facilities, or shortage of laboratory equipment, have not been approved. Many of these nonapproved institutions might easily be approved if they sought such approval, and still more of them, including some that have sought and not obtained approval, will graduate excellent students, who will stand up well along with the best of the approved schools. One-fourth of the Ph.D. degrees in chemistry are annually awarded to graduates of nonapproved schools or to graduates of approved schools who have taken a nonapproved course of training for the B.S. degree.

However, with three-fourths of the Ph.D. candidates in chemistry being ACS-certified graduates and with a production of about 1000 Ph.D. degrees a year in chemistry (Fig. 7), it is possible to evaluate the production rate and source. It appears that about 33 percent of the ACS-certified graduates obtain Ph.D.'s. This in itself would imply that there is an adequate supply if the certified status is, of itself, a reliable indication of quality or capacity for advanced work. Some feel, however, that perhaps not more than a third of the career graduates in chemistry should eventually obtain the Ph.D. With the increase in number of college students and graduates over the past two decades, there has been an increase in the number of B.S. degrees in chemistry, as recorded by the Office of Education (*7*). In the past 9 years, it may be noted (Fig. 6), the number of B.S. degrees in chemistry has risen from 5500 in 1954 to 8300 in 1962. In this same period, the number of institutions giving B.S. degrees in chemistry has risen from 800 in 1954 to 830 in 1962, and the average number of B.S. degrees in chemistry per school each year has risen from 7 in 1954 to 10 in 1962.

The real question is whether this increase in number of B.S. degrees in chemistry is due to background or nonprofessional majors, who generally take a minimum-requirement course, or whether there has been a parallel increase in the ACS-certified or professional chemistry majors. A preliminary examination of the data on ACS-certified degrees (*16*) in Fig. 6 would seem to indicate a parallel increase, for the number of degrees has risen from 1800 in 1954 to 2600 in 1962. However, one must take into consideration the number of approved schools, for this number is also steadily increasing as new schools are examined and approved, and one must realize that there are many good schools, producing a fourth of the Ph.D. candidates in chemistry, that have as yet not been approved. If we divide the number of ACS-certified degrees obtained by the number of ACS-approved schools, we note that a nearly constant number of 8.5 degrees per school is being granted, and there is evidence of saturation or leveling off during this period of constant population in the age group. Lest some may feel that the leveling off is a spurious effect arising because new schools are smaller in size (this does

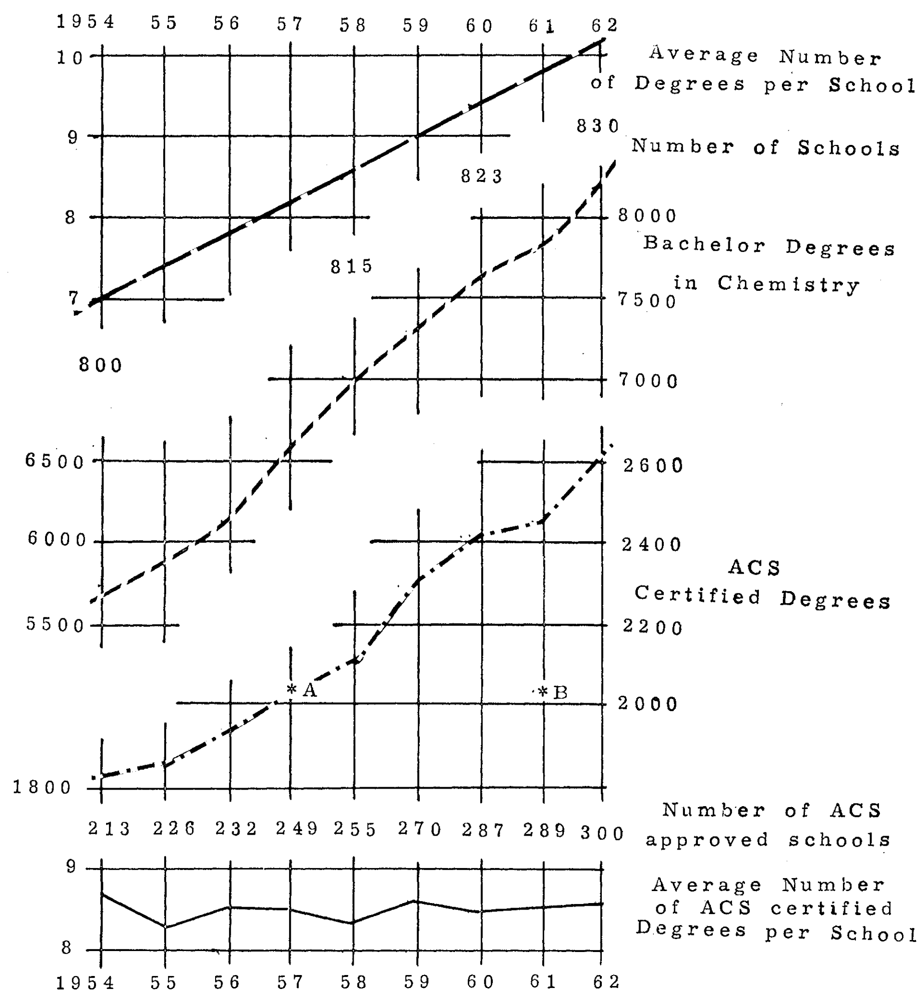

Fig. 6. Comparative data on the rates of production of all bachelor degrees in chemistry and of ACS-certified degrees in chemistry (*7–11, 16*).

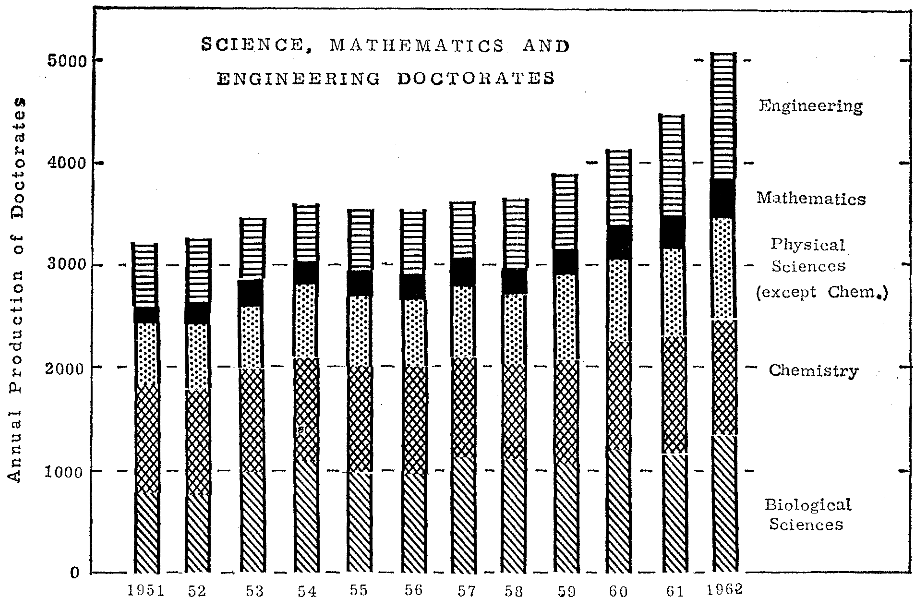

Fig. 7. Annual production of Ph.D. degrees in science and engineering. Note the nearly constant production in the 1950's and the slight rise in the 1960's (*7–11, 16*).

not appear to be the case from the known schools being admitted in recent years), the same schools which were approved in 1957 (Fig. 6, point **A*) were examined for the number of ACS-certified graduates in 1961, and the total number is indicated by point **B*. The constant production of ACS-certified graduates or professionally trained chemists and the similar constant production, over the same period, of Ph.D.'s in chemistry (Fig. 7) tend to support the general thesis which I have been developing, that we are approaching a ceiling of maximum utilization in the supply of qualified scientific personnel. With the coming expansion in the college age group from 1963 to 1970, we would expect a corresponding expansion in the number of qualified students, one which should correspond to the total number in the age group.

A flow-pattern analysis (Fig. 8) provides some interesting information on the production of Ph.D. and ACS-certified B.S. degrees in chemistry. It is important to note that ACS-approved schools may produce both the ACS-certified graduates and regular or background B.S. majors in chemistry. Some of the students who are not certified may have taken some special courses, rather than those specified for certification, and thus, while they may be excellent students, are not certified. They may, however, go on for an advanced degree, and these students, along with the graduates of quality from schools which are not certified, become the candidates for about a fourth of the Ph.D. degrees.

It becomes quite apparent that there are two main types of science majors for the B.S. in chemistry, although there are, of course, many who may complete less than the required curricula for the certified degree and more than the minimum for a general B.S. background degree. It is also evident that there are two different philosophies of scientific (chemical) education, which are rather sharply divided. Either a school provides a program solely for the professionally minded chemist or else it provides for both the professionally minded and the nonprofessionally oriented chemist (background major). There are a few schools which provide only for the nonprofessional; one must recognize that, of the some 1800 degree-granting institutions of higher learning in this country, only 830 offer a B.S. in chemistry, and some of those that do offer chemistry majors are oriented toward education, medicine, law, business, or other major cultural area other than basic science.

There were in 1962 some 300 approved schools under the ACS program, and these included the 110 schools which also gave Ph.D. degrees in chemistry. Within the schools producing 90 percent of the chemistry Ph.D.'s there is the same division into two types of schools that is found in the non-Ph.D.-granting schools. In one group essentially all graduates are ACS-certified, while in the other group about half the graduates are ACS-certified and the other half are general or background majors.

A study of the ACS-certified graduates over the last 5-year period (1958 to 1962) and of recipients of the Ph.D. and general B.S. degrees has produced some interesting patterns and trends (Fig. 9). The 70 schools which produce 90 percent of our Ph.D.'s also produced about 40 percent of the ACS-certified graduates, as well as 10 percent of the noncertified graduates. In all, they produced 25 percent of the B.S. degrees in chemistry. In some schools, such as Iowa State, Massachusetts Institute of Technology, Cornell, Princeton, Brown, Maryland, the Uni-

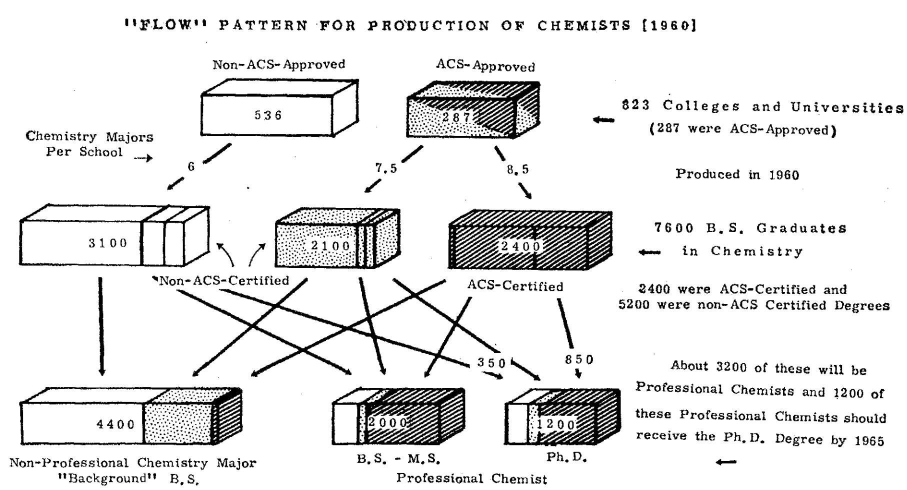

Fig. 8. "Flow" pattern for the production of chemists (1960) (*16*). Note that 75 percent of the Ph.D.'s will be received by ACS-certified graduates, and that 35 percent of the ACS-certified graduates will go on to obtain a Ph.D. degree. About 20 percent of the graduates from non-ACS-approved curricula or schools will go on with professional education, and 6 percent will obtain Ph.D. degrees.

versity of California at Los Angeles, and California Institute of Technology, essentially all recipients of the B.S. degrees in chemistry were ACS-certified. In other schools, such as Illinois, New York University, Northwestern, Rutgers, Columbia, Harvard, the University of Iowa, and Purdue, about 50 percent of the recipients of the B.S. degree in chemistry were noncertified. (It is of interest to note that, in the non-Ph.D-granting, ACS-approved schools, there is this same division, some schools giving only ACS-certified B.S. degrees, others giving about an equal number of ACS-certified and noncertified degrees.)

Elimination of the 70 schools producing 90 percent of the Ph.D.'s and 40 percent of the ACS-certified B.S. degrees leaves 230 approved schools. These 230 schools include 40 schools which produced the remaining 10 percent of the Ph.D.'s, and these 40 schools, together with the 190 other approved schools, produced about 60 percent of the ACS-certified degrees and 25 percent of the noncertified degrees. Over a 5-year period, it appears, about a third of the total number of B.S. degrees in chemistry were ACS-certified (11,881 out of 36,116). These certified degrees, however, come from only 300 out of the 830 degree-granting institutions, and the remaining 530 schools which, by reason of choice, size, or other factors, are not as yet ACS-approved, produce many students of superior quality; this is indicated by their acceptance and success as graduate students in our leading graduate schools (Fig. 9). Over 25 percent of the Ph.D. candidates are graduates from these nonapproved schools, and many of these have achieved outstanding recognition in science. These noncertified graduates constitute about 22 percent of the Ph.D.'s in chemistry, and thus one can estimate that of the 36,000 B.S. graduates in chemistry in the 5-year period (1958 to 1962), some 12,000 ACS-certified and about 4000 noncertified graduates, or a total of 16,000 (45 percent of all chemistry B.S. degrees) were professionally oriented. About a third of these professionally oriented students attain the Ph.D. degree, and the number of Ph.D. degrees in chemistry has been reasonably constant at about 1000 a year for the past decade (Fig. 7).

There does not appear to be any reasonable method of identifying the number of professionally oriented graduating students from the non-ACS-approved schools. If we had such a method of identification, we might well confirm a suspicion that the excess of noncertified students (Fig. 9, area *A*) is probably composed of some less well qualified students, and that the number of highly qualified, although noncertified, students is probably tapering off in the schools in groups *c*, *d*, and *e*, in much the same proportion that the number of ACS-certified students is. This tapering off, combined with an increased utilization of the school's own graduates as Ph.D. candidates, provides additional evidence of the approach to a ceiling in the supply of qualified candidates. The completion of the Ph.D. degree by about a third of the professionally oriented B.S. graduates is, in itself, an indication of the approach to this ceiling. It must be obvious that there will have to be some who are trained at the B.S. and M.S. levels for specific types of work, and that scientists cannot be "all chiefs and no indians."

In Fig. 9 it may be noted that, among the top 25 schools which produce some 55 percent of the Ph.D.'s, less than 10 percent of the students obtained their B.S. degree from the same school as their Ph.D. degree. There is a fairly wide variation among the schools which provide this 10-percent average, some of the major schools accepting essentially none of their own B.S. graduates and others taking from 15 to 20 percent. It would appear that, in the area of chemistry, it is more or less traditional that one should go to another school for the Ph.D. after completion of the B.S. This tradition does not ap-

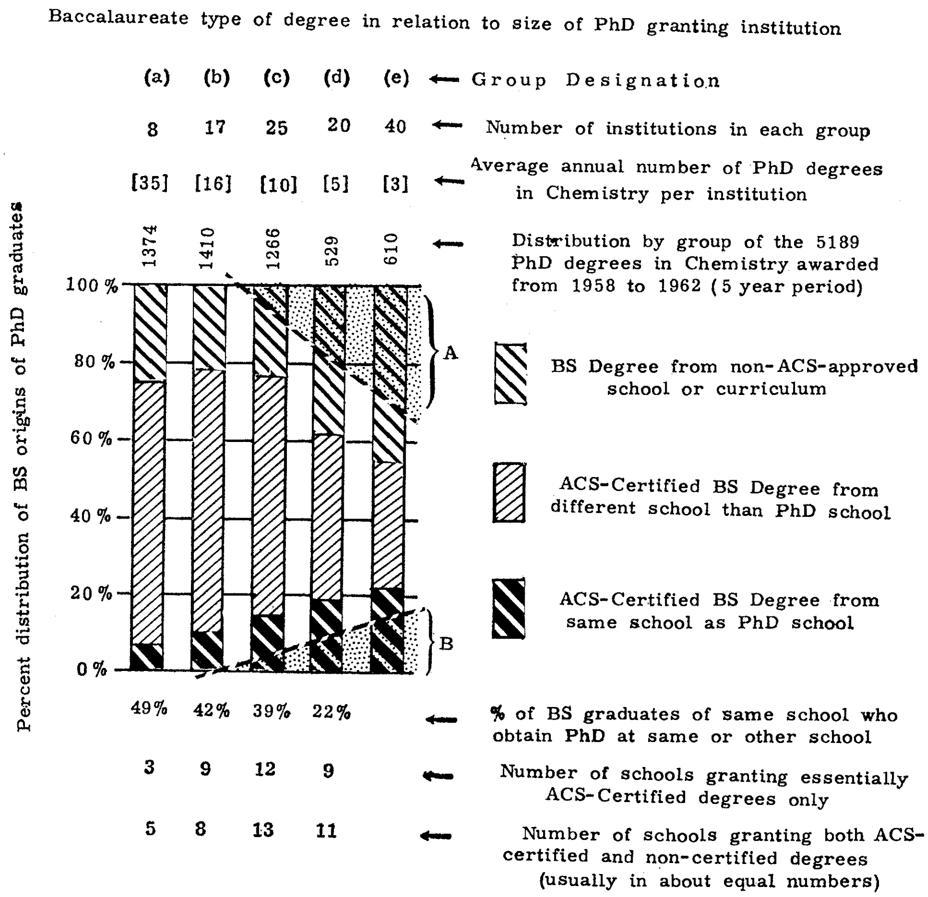

Fig. 9. Production of Ph.D. degrees in chemistry (1958–62) studied by group, according to the size of the graduate school (*7–11,16*). The approach to the ceiling, due to maximum utilization of the available supply, is indicated by the increase *A* in the proportion of non-ACS-certified graduates in the smaller graduate schools, over and above the proportion in groups *a* and *b* of about one noncertified to four ACS-certified graduates. In the last decade there has been a decrease in the percentage of non-ACS-certified Ph.D. candidates in groups *a* and *b*, which would be expected as the number of approved schools is gradually increased. At the same time, there has been an increase in the number of non-ACS-certified graduate students in groups *d* and *e*, so the overall percentage of non-ACS-certified graduate students has remained at about 26 percent in the 5-year period under study. The data below the abscissa refer to the production and subsequent training of B.S. graduates in chemistry by the same schools that give the graduate training.

pear to be as firmly developed in other sciences, especially the newer areas, where the number of schools with competence in the field may be limited. This effect may, in itself, be a parameter of a well-established and well-developed educational program. However, the expansion of this group above about 10 percent (Fig. 9, area *B*) may indicate recruitment difficulties or limitation of supply.

There is a serious problem in the production of science majors which is often neglected by those schools or professors who apparently have no time or patience to deal with students who are not professionally oriented toward their major science subject. In Fig. 9 it is indicated that about half of the major Ph.D.-granting institutions do not provide for a noncertified or background degree in chemistry. Some, it would appear, go even a step farther and essentially cultivate only Ph.D.-oriented bachelor majors, as is indicated by the fact that 49 percent of the ACS-certified bachelor graduates in chemistry, from the top eight graduate schools in the country, obtained Ph.D. degrees, whereas the average proportion of the ACS-certified graduates who obtained Ph.D. degrees was 33 percent. It does not seem reasonable that when, according to the national average, about 2 percent of the college graduates major in chemistry (7600 out of 400,000), a school with over 20,000 students and about 2500 in the annual graduating class should, over a 5-year period, average fewer than five B.S. graduates in chemistry per year. This school, incidentally, produces some three times as many Ph.D. degrees in chemistry a year as it produces B.S. degrees in chemistry. In other, equally large schools, about 2 percent of the graduates are chemistry majors, and about half of these are ACS-certified. Many small schools, with less than 10 percent of the enrollment of the larger universities, produce two or three times the number of ACS-certified B.S. graduates and Ph.D. candidates that the larger universities do.

The Liberal Arts College as a Source of Ph.D. Candidates

Two-thirds of the Ph.D. candidates do not originate in the major Ph.D.-granting institutions (the top 50 graduate schools which produce 80 percent of the Ph.D. degrees in chemistry). In all probability, close to 60 percent of the Ph.D. candidates obtain their B.S. degrees from non-Ph.D.-granting institutions (that is, institutions which grant on the average less than one Ph.D. in chemistry per year), and included in this 60 percent are the 25 percent of the Ph.D. degrees known to be awarded to B.S. graduates from schools which are not ACS-approved.

It would appear that 90 percent of the Ph.D. degrees in chemistry are granted by schools that produce only 30 percent of the "raw material" in the form of B.S. majors in chemistry who go on to complete their Ph.D. degree. There have been previous studies of the baccalaureate origins of Ph.D. candidates (*15*, *18*), and others are now in progress. Some preliminary data from these studies are shown in Fig. 9, on the percentages of graduates of various groups of schools who have gone on for Ph.D. degrees at the same or other institutions. While the national averages for the ACS-certified and the professionally oriented major from the non-approved schools show that 33 percent of the students in this group go on for their Ph.D., it is evident that, in the leading schools, groups *a* and *b*, over 40 percent continue for a Ph.D., and that in group *d*, which includes many of the smaller graduate schools, only 22 percent of the professionally oriented B.S. majors go on for a Ph.D. and a fairly large portion of these continue on in the same institution. This effect is probably even greater in group *e*, for which complete data were not available. On the other hand, with some 60 percent of the Ph.D. candidates coming from non-Ph.D.-granting institutions, it must be obvious that the percentage of professionally oriented majors who go on for a Ph.D. must be near the national average of 33 percent. It would appear that the major sources of the raw material for Ph.D.'s in chemistry are the "lean" institutions, without major subsidies, and yet the proposals to increase and improve the supply of our scientists seem to be directed toward further support of those schools which produce only a small portion of the B.S. graduates who become Ph.D. candidates. The schools which produce the major supply of our Ph.D. candidates are suffering, and are handicapped by a lack of competent younger instructors; such instructors have been enticed away to subsidized work in programs which tend to distort our supply.

The "bottleneck"—if there is one—in the supply and production of chemists and, in particular, Ph.D.'s in chemistry is not a matter of facilities; a recent survey has indicated that most institutions could absorb additional students (*11*). It is not a lack of scholarships, fellowships, and teaching assistantships; these are not in short supply (*19*), and many of our smaller graduate schools are hard pressed to fill available teaching-assistant openings. The limitation appears to be a shortage in the number of qualified graduate students with an ability and desire to work toward an advanced degree. This limited supply is a direct indication of the approach to a ceiling of maximum utilization. Granting subsidies to the schools which produce the major supply of Ph.D. students may not appreciably increase the number of candidates, for we are apparently at or near the maximum available proportion (the number should increase with the population increase in the next decade). Such subsidies would, however, make it possible to provide better training, and it should be our objective, once the supply limits are reached, to produce better scientists from those who are qualified, rather than more by including those who are not fully qualified. It is to be noted that there has been an increase, in recent years, in the proportion of noncertified B.S. degrees as compared with a rather constant supply of ACS-certified degrees. This would imply that the increase in chemistry majors above the figure expected from increases in the student population is an increase in students who are not professionally oriented and who are not inclined toward nor capable of further advanced work in the technical area. An increase in the production of professionally oriented students above the ceiling of maximum utilization is to be expected only if the standards or requirements are reduced.

An important fact about the system for professional training in chemistry is the opportunity it offers to shift from or to a professional or nonprofessional status, as may be dictated by the student's ability, interest, and desire. Such shifts can be made with a minimum penalty in extra time and courses and even at a relatively late period in the student's course. In many other areas of study the student is essentially trapped and can go only up or out. Because of this flexibility, and the broad choices available even within the subject of chemistry, there is reason to believe that we are capturing just about all the available or potential chemists in the student group. In many schools we are, however, neglecting the problem of subprofessional training and background major for those who aspire to be an "extra pair of hands" to the research worker, or who need the science background for a career in teaching, law, business, medicine, or other profession. The background or subprofessional major is an important area which is being neglected in some of our major institutions.

In major universities where the chemistry department shows an indifference to the nonprofessional major or course, and especially if the only students encouraged to take a B.S. major are potential Ph.D.'s, one will often find other departments, such as education, agriculture, biology, or general studies, offering courses in chemistry (usually under a disguised title) which should be given by the chemistry department. Eventually, this leads to separate departments, separate graduate work, and a proliferation of courses and degrees. The shedding of the responsibility to provide nonmajor and nonprofessional courses and degrees leads to colleges of general studies and to standards for degrees that are lower than they would be if the departments would share in service as well as professional training and guidance. We should be pleased that a large part of our student body elects to "major" in science, even though the student does so only as a general education background for teaching, business, law, medicine, being a citizen, or being a housewife. There are, unfortunately, too many departments—even colleges—which pride themselves on restricting the communication of knowledge to the very few who will commit themselves to the highest level of attainment in the profession involved (*11*).

Science, in its professional training, should be as restrictive as many other professional areas, such as law, medicine, or education, but we should also provide training and understanding for the nonprofessional. The failure of science departments to provide reasonable major curricula for the B.S. and even the M.S. for those who wish to make science teaching in our public schools a career has essentially forced these students to major in education rather than science and, in some areas, has even forced the education departments to give the science courses which should have been given within the science areas.

Areas of science and engineering are continually changing in content and character as new advances take place. It is not surprising in this age of the computer and of automation to have a marked increase in mathematics majors. Much of this should have been in a mathematics-engineering area, similar to chemical engineering as a bridge between chemistry and engineering. The failure to make this bridge has, in many areas, created excessive numbers of mathematics majors of those who do not contemplate an ivory-tower research career but, rather, desire to work in computer technology and statistical studies. In the reverse sense, one finds, in many professional areas, including engineering, pharmacy, and medicine, proposals for Ph.D. programs which are, in fact, basic research in such pure-science areas as physics, anatomy, chemistry, and mathematics. Serious consideration should be given to a continuous realignment of technological courses and departments. For advanced work in professional subjects such as medicine, law, engineering, and education, institutions should be encouraged to give corresponding advanced professional degrees, such as M.D., J.D., D.Eng., and D.Ed.

One must be a bit optimistic to believe that, in a space of 15 years, mathematics could expand the number of majors by 1000 percent [in 1955 there were 4000 mathematics majors (*20*), and it is predicted that in 1970 there will be 44,000]. Such a proposal has recently been made (*3*), even though, in the same period, the college-age population is not expected even to double (an increase from 2.1 to 3.5 million is predicted) (see Fig. 3). The linear extrapolation of such predictions (Fig. 4) does provide for a steady growth, but the extension for any considerable period in the future provides totals which seem to be either highly impractical or even impossible (*19*). Any projected growth rate which exceeds the population growth rate cannot, at our high level of technology, be continued for any extended time in the future without materially upsetting our technological balance and other programs in education and technology.

Although the annual number of 18-year-olds in the population in the period 1961–1963 should be about 8 percent higher than over the previous 5 years (Fig. 3), the first-time enrollments are expanding at a rate of only about 1.5 percent a year. On the other hand the total college enrollments are expanding at a rate of about 8 percent a year during this 1961–63 period. This is a distinct reversal of the trend for the previous 5 years (1956–61), in which, with a nearly constant population of 18-year-olds, first-time enrollments rose an average of 8 percent per year and total enrollments rose only about 6 percent per year (*8*).

The combination of these two effects in 1961–63—stabilization of first-time enrollments to a nearly constant number and expansion of total enrollments—can best be explained as a result of tightening of admission requirements and a rejection of a higher proportion of the less qualified. An increase in quality should result in fewer failures and a reduction in the dropouts due to poor academic performance. Privately operated schools, where admission qualifications can be raised without political concurrence, have in fact shown a 1-percent drop in first-time enrollments for the past 2 years, although their total enrollments have risen about 4 percent a year in the same period.

As one dean pointed out, "Our students are better than ever," and well they should be, because for 3 years his school has held to a raised entrance requirement. His major problem now is that junior and senior classes are larger than expected, because of the higher retention rate, and good teachers in upper-division areas seem to be hard to recruit in today's competitive market. Ultimately the values for enrollment should stabilize and become a function of the first-time admissions; both these values may, of course, change as standards of the population change.

Conclusion

The members of the science and engineering professions should not be worried about any leveling off of numbers or proportion of graduates as long as proper standards of quality are maintained. They should, however, be worried about any movement to increase the number of graduates by lowering standards of accomplishment. They should also be worried about programs of utilization which require more personnel than can be produced without lowering standards, and about failure to provide personnel for essential areas such as undergraduate teaching in our smaller liberal arts colleges.

The approaching ceiling in the supply of manpower in science and engineering requires emphasis on more than increased numbers if we are to increase the strength of our technology. We need to improve the quality of our educational program through better selection of our students and acceleration and strengthening of courses based on the higher average competence attained through better selection. To compensate for the limitation on the number of students selected for high-level graduate programs, we must produce an added number of technicians and technical assistants through special courses and junior-college-level terminal curricula. Within broad areas we should develop background or nonprofessional majors to improve the public understanding and appreciation of science and to incorporate science and technology with other areas of culture.

Professional degrees in engineering and technology should be established to parallel the professional degrees in medicine, law, and education, the Ph.D. degree being thus retained for basic research in the fundamental areas.

The educational procedures and curricula of our colleges and universities need some careful study and revision in order that both elementary and advanced training may be improved and that there may be adequate challenge to stimulate the interest and ability of students who are professionally oriented and of those who are not. For example, in mathematics, we need an applied mathematics curriculum, probably in engineering, to match the well-developed chemical engineering and basic chemistry combination. The problem of 5-year engineering and other combination curricula needs to be met with a proper recognition of the master's degree at the end of the 5-year program and a general acceptance of the masters degree, like the bachelor's degree, as an in-course degree of prestige which may either be terminal or lead toward a Ph.D. The M.S. degree definitely should not be treated as a consolation or deficiency award.

Nationally, we need to produce a better organization and planning of our scientific and technical programs, with reasonable priorities in personnel, funds, and facilities to education, government, and industry as well as to areas of interest such as health, space, defense research, education, and technology (*21*).

Responsibilities for our scientific programs, as they reach ceilings or limitations, must be shared by other areas of the world, and developing areas should be expected to increase both their financial support and their contributions to knowledge as they grow and approach our economic and cultural levels. While not considered a part of this study, the recent discussion about employment of foreign-trained scientists for positions in the United States may well be an indication of approaching ceilings in the supply of scientists in some areas.

All of us realize that there are limits of growth, speed, size, or education. As we approach these limits our rate of increase will slow down, and we will approach the ceiling gradually. It should be recognized that it is not easy to approach close to a ceiling, for the last few advances may be as difficult to achieve and maintain as much of the earlier gain.

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