The Final Report of the Goals of Engineering Education study is published in the Journal of Engineering Education so that every member of the American Society for Engineering Education will have a copy and will be made aware of the importance of the report as it relates to trends for the future. It is also the hope of the Goals Committee that the report will generate constructive discussion. Eric A. Walker, Director of the Goals study, says, "This Final Report will remain on the desk of every engineering teacher for many years to come. Like the previous studies of engineering education, it will have an impact on curricula, staff, and students, as well as on industry and government, the employers of our graduates."

# FINAL REPORT: GOALS OF ENGINEERING EDUCATION

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**ERIC A. WALKER** **JOSEPH M. PETTIT** **GEORGE A. HAWKINS**

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# Goals of Engineering Education

# FINAL REPORT
# OF
# THE GOALS COMMITTEE


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**AMERICAN SOCIETY FOR ENGINEERING EDUCATION**
**2100 Pennsylvania Ave., N.W., Washington, D.C. 20037**
**JANUARY 1968**

# PREFACE

This Report was prepared by the Goals staff based upon comments and suggestions received from literally thousands of engineers, engineering educators and other individuals and groups concerned with engineering education. However, it is not a consensus report based upon a majority opinion of either the Goals staff, the members of the boards of analysts, engineers, or engineering educators.

The members of the Goals Committee, Eric A. Walker, Joseph M. Pettit, and George A. Hawkins, assume full responsibility for its content. However, they gratefully acknowledge the assistance given to them in its preparation by the other members of the Goals staff, the undergraduate and graduate boards of analysts, as well as many other individuals and organizations who have given their suggestions, advice and council.

Section A was prepared by the Chairman of the Committee, Eric A. Walker, and his assistant, Benjamin Nead of the Pennsylvania State University, largely based upon Parts B, C and D as well as a paper presented by Dr. Walker at the 1966 Annual Meeting of ASEE and reproduced in the September 1966 issue of *Journal of Engineering Education.*

Sections B and C were prepared by George A. Hawkins, William K. LeBold, Warren E. Howland and Robert Perrucci of Purdue University. Section D was prepared by Joseph M. Pettit and James M. Gere of Stanford University.

The Goals Committee and the Goals staff would like to acknowledge the contributions made throughout the study by members of the graduate and undergraduate boards of analysts, the consultants and advisors, and by officers of the ASEE, including Past Presidents Kurt F. Wendt, George D. Lobingier and Robert H. Roy and the Executive Secretary W. Leighton Collins.

Acknowledgment should be made of the many important contributions by the Institutional and Organizational Study Committees of engineering schools, industries and governmental organizations, and professional societies, as well as by individual engineers and engineering educators, and other interested parties who contributed directly and indirectly to this study.

The National Science Foundation provided most of the necessary funds for conducting this study. Their interest and cooperation are gratefully acknowledged and sincerely appreciated.

# Part A. Introductory Summary

THIS REPORT represents the culmination of a series of investigations carried out during the past five years involving the accumulation of a large mass of data from engineering educators, practicing engineers, and employers of engineering talent throughout the United States. A Preliminary Report, an Interim Report, and a number of other documents issued while the study was in progress have been widely discussed and commented upon. These comments, together with the basic data accumulated, have been digested and analyzed in an effort to fulfill the charge originally placed upon the Goals Committee by the American Society for Engineering Education.

### *Aims of the Goals Study*

As its name implies, the Goals Study represents an attempt to indicate, in broad and general terms, the direction which engineering education must take if it is to meet the demands of the future. It is neither a detailed evaluation of present practices nor a consensus of current suggestions for improvement, but an effort to delineate significant trends in engineering education and to relate these trends to the future needs of practicing engineers.

### *Self-Analysis in Engineering Education*

To a larger extent than most other academic disciplines, engineering education has been the subject of extensive study. During the past fifty years, a number of major investigations have exerted a significant influence upon its development. The Mann report of 1918 (Ref. A-1), the Wickenden investigation during the 1920's (Ref. A-2), the two Hammond studies immediately preceding and following World War II (Ref. A-3, A-4), the Grinter evaluation of 1955 (Ref. A-5), and the Burdell report of 1956 (Ref. A-6)—these and other less exhaustive studies have each, in turn, examined the practices of engineering educators in the light of changing needs and have provided the basis for a conscious effort to keep educational programs attuned to the requirements of engineering practice.

The general success of this continual self-analysis and consequent modification of educational programs is evident in the current attitudes of the employers of engineers. For the most part there is agreement that engineering educators are doing a competent job, that they understand the needs of engineering practice and are providing engineering students with the knowledge and skills necessary to meet present-day requirements. There are, to be sure, a variety of suggestions for improvement in limited areas, but in general there is little demand for radical changes in academic programs.

### Continued Development to Meet Future Needs

At the same time there is clear evidence that forward-looking educators and employers alike are conscious of the need for continued development and growth in engineering education. The rapid accumulation of new knowledge of all kinds in recent years, the accelerating pace of technological development, and the growing complexity of social, economic, and technical interrelationships in modern society demand a careful and continuing reappraisal of all educational practices, in terms not only of their adequacy for meeting present needs but of their ability to satisfy the much more demanding requirements of the future. The task of educators is to understand the forces and trends at work in the process and to assure themselves that changes are made at the proper time and in the right direction.

In terms of its past development and present position, where is engineering education going? In relation to the forces generally at work in higher education, where will engineering education stand ten to twenty years hence? Will it be producing engineers who can meet the likely needs of industry, government, and society in general in the year 2000? What, if anything, should be done to direct the growth of engineering education and assure its proper development? These are the questions that must be faced by engineering educators today.

### Trends at Work in Engineering Education

Broadly considered, the history of engineering education in the last half century reflects the influence of two strong trends, both clearly recognized as long ago as the Wickenden investigation and both evident in the educational developments that have resulted from this and other studies.

On the one hand there has been a conscious desire for unity of purpose in engineering education and for uniformity of standards and practices within the various branches. There has been a growing tendency to emphasize fundamentals and to provide the engineer with a basic technical knowledge that would enable him to practice in a variety of occupations. The widespread acceptance of the uniform first year is an indication of this trend, as is the more recent development of the engineering sciences as basic to all engineering education, a development supported by the Grinter study and fostered by the Engineers' Council for Professional Development.

On the other hand there has been, at the same time, a strong tendency toward broadening the content of engineering programs in all branches. Wickenden recognized the importance of providing engineers—regardless of their special fields of interest—with some training in economics and in management, and he emphasized the need for rounding out the engineer's technical knowledge with social and humanistic studies. Hammond placed even greater emphasis on this matter of broad general knowledge and suggested that a large part of the student's specialized technical education should be postponed to the senior year or even beyond. The Burdell study added fresh impetus to the growing recognition of the importance of the humanities and social sciences. And more recently, there has been acceptance of the need for other types of training—statistics, for example, and computer programming—thus adding further to the diversity and breadth of material considered essential to the basic needs of all engineers.

### Engineering As a Liberal Science Program

The general result of these trends has been to make engineering a unique type of program in American higher education—a program which, in effect, has attempted to provide within the confines of a traditional four-year period both a broad general education and a specialized technical education of great and growing compexity.

The broadening of engineering education has been remarkably successful. Whether by conscious design or not, the typical four-year engineering program has gradually developed from a group of occupationally oriented specialities into a liberal program of rather general nature, in some respects the counterpart in the area of science and technology of the broadly based general education that has been traditionally offered in the liberal arts. At the same time, the typical engineering program goes beyond the mere accumulation of a variety of general knowledge. Although it is centered around mathematics and the physical sciences, it recognizes the importance of the social sciences, the humanities, and the communication skills, and, through its emphasis upon problem-solving, it provides the student with an opportunity to integrate his knowledge and to apply it specifically to the problems of a technologically oriented society.

But this broadening of the engineering program has created difficulties. It has necessarily limited the time that could be devoted to technical specialization, and it has done so in a period when knowledge has been growing at an accelerating pace and when the technical demands on engineering graduates have become greater than ever before. In spite of continued efforts to stress fundamentals and to streamline both the technical and non-technical aspects of their programs, engineering educators have found themselves in a dilemma. If an engineer is to have the broad general education which his role in modern society demands and at the same time be trained to the high level of proficiency required in many specialized areas of modern technology, how—in the light of the growing demands from both quarters—can the job be done within the confines of the traditional four-year program?

### *New Diversity in Educational Practices*

The seriousness of the situation is evident in the variety of attempts that have been made to alleviate it. In some branches of engineering, the baccalaureate program has been lengthened to five years as a regular requirement, and at a few institutions this practice has been extended to all engineering programs. In some cases, the growing demands of technological specialization have been met by an increasing use of on-the-job or professional training within industry. In a number of areas, there has been increased recognition of the need for graduate study, especially for those students who are preparing themselves for occupations in research and development, or in fields where new knowledge is being rapidly developed.

At the same time in a few fields of engineering practice it is felt by both educators and employers of engineers that the current four-year program is adequate for their needs and will remain so in the foreseeable future.

In short, it seems evident that we are witnessing a trend toward a new kind of diversity in engineering education—a diversity which is likely to increase as new technologies develop and older ones change in character.

### *Increasing Demand for Engineers*

Moreover there is little doubt that, in addition to new varieties of occupational specialties, the future will bring an increasing demand for larger numbers of engineers in all areas. The proportion of engineers in the total work force in the United States has been growing for many years, and there is every reason to believe that this trend will continue. Indeed, with the rapid development of scientific knowledge since World War II and the growing demand to put this knowledge to use in the production of goods and services that can help the economy grow, the shortage of technologically trained personnel has become a matter of national concern. Recent projections made by educational, governmental and professional groups agree that society's needs in the future will call for engineering and technological talent on a scale never before seen. It is recommended, therefore, that opportunities for engineering education be greatly expanded not only in existing institutions but also in new institutions being created to meet the mounting demands for higher education in general.

### *Growing Need for Breadth in Engineering Programs*

Yet in spite of the pressure for occupational specialties and for the training of larger numbers of engineering personnel, it seems unlikely that there will be any reversal of the trend toward broadening the basic education of the engineer. On the contrary, it is generally recognized that the engineer of the future—regardless of his special interests—should be provided with a fuller and richer understanding of the social and economic forces that will influence and be influenced by his technology. The probability is that the humanities and social sciences, and the life sciences as well, will be given increased emphasis in engineering curricula, and that efforts will be made to develop more effective ways of integrating these and other studies into engineering programs. Engineering education has been and should be encouraged to continue to be an important and significant type of general education needed in a technological-scientific society.

The engineering program includes the natural sciences, social sciences, humanities, and communication arts and a strong core of mathematics, engineering science, and analysis. It brings these intellectual disciplines and fields of knowledge to bear on some of the real and contemporary problems of society and develops in the student a sensitivity to these problems. Thus it provides a basis for a liberal education appropriate to the times. Engineering colleges and the engineering profession are encouraged to develop this important educational potentiality more fully, not only by formulating a philosophy of general education but also by establishing procedures for implementing such a philosophy in an engineering setting.

It is encouraging to learn that this need is recognized and that such a study, sponsored by the ASEE and financed by a grant from the Carnegie Foundation, is now underway. The study will focus "on goals for the humanities and social sciences that are relevant to the changing character of society and the changing role of the engineer." It will "include guide lines for achieving the goals" (Ref. A-7).

### *Increasing Level of Technical Demands*

It is equally clear, however, that the continuing development of breadth in basic engineering education must not be achieved at the expense of specialized technical competence. Beyond the need to satisfy the requirements of a wide variety of occupational demands and the necessity for broad general knowledge, there remains the even more important task of providing the engineer of the future with a very high level of technical proficiency in his specialty. The rapid rate of advance of scientific knowledge and the growth in complexity in all technological endeavor, together with the continuing development of interdisciplinary activity, will place increasing demands on engineering skill.

In spite of the other methods which to date have proved more or less satisfactory in accomplishing this end, the general trend seems definitely to be in the direction of a year or more of graduate study. This practice has already gained foothold in some engineering specialties, and in a few engineering schools it has been made a general requirement in all branches of engineering. Elsewhere, many of the more capable and ambitious students are themselves recognizing the advantages of proceeding beyond the baccalaureate. There is evidence, too, that in many areas of industry and government, employers expect increasingly to be seeking engineers with advanced degrees. With the growing complexity of modern technology, there is every reason to believe that these tendencies will spread. Increasingly the engineering student will need graduate-level education for the kind of intensive and comprehensive study required for adequate self-development beyond his baccalaureate program.

Indeed, the remarkable growth of graduate study in all fields of education is one of the most significant trends of our times. Since 1950, the number of students in all areas who have continued their education beyond the baccalaureate level has been doubled, and there is every indication that this growth will continue. In engineering, the number of master's degrees awarded annually has grown by almost 2.8 times during the same period, and the number of doctorates by over 4 times. The projections made in the Goals Study, as well as others by the Office of Education and the Engineers Joint Council, all indicate substantial and continued growth at the graduate level.

### *The Basic Professional Degree*

What seems to be happening is that from every quarter—practicing engineers, employers of engineering talent, educators, and students themselves—pressure is being exerted to raise the level of basic engineering education and to include in the preparation for general engineering practice not merely additional undergraduate courses but at least a year of training at the graduate level—in short, to increase the generally accepted academic requirements for entry into the engineering profession. There is little doubt that during the next decade we will witness a rapidly developing consensus that the master's degree should be considered the basic professional degree in engineering.

### *Flexibility and Variety in Engineering Education*

Although the requirements for basic engineering education will almost certainly be raised to the master's level, the diverse demands of the future can be met only through the provision of increased opportunity for adequate education at all levels and in all areas of engineering interest. In addition to the basic program, opportunities must be enlarged on the one hand for the education of engineering technicians and technologists* and on the other for advanced engineering education leading to degrees beyond the master's. And, at all levels, provision must be made for continuing education. Moreover, within the framework of the programs offered, there must be increased flexibility and greater freedom in course selection, coupled with effective advising systems designed to accommodate the differing aims and talents of individual students.

Diversity in educational practices, already noted as a significant development, is likely to grow. It seems evident that engineering practice can best be served by the provision of a multiplicity of offerings that provide not only for increased specialization within the various branches of engineering but that are aimed directly at preparing students for a variety of functions, including design, research, development, management, operations, and so on. As engineering schools grow and new ones develop, individual schools will emphasize a limited number of these areas, depending upon the kinds of students, faculties and facilities they possess or desire to develop. In many cases, more flexible programs will be required to meet the varied backgrounds of the expanding numbers and proportions of students entering undergraduate engineering at the junior year from community colleges, or at the beginning of the graduate years from other colleges and universities.

Smaller institutions will find it desirable to limit their offerings to a few programs of high quality rather than extend themselves beyond their capacities. Cooperative arrangements will no doubt be worked out on a regional basis to meet specific needs. Some institutions will continue to confine their efforts to the baccalaureate level and arrange for the transfer of students desiring to complete the requirements for a professional degree to another institution. Thoughtfully developed experimentation should be encouraged.

### *Basic Engineering Education*

Yet at the same time it is essential that high quality be maintained in engineering programs. Perhaps the greatest challenge facing engineering educators today is that of achieving a workable balance between a thorough-going flexibility and variety on the one hand and a reasonable uniformity of standards and goals on the other. As envisioned, the basic engineering program—baccalaureate plus master's—seems to offer the opportunity needed to achieve this goal. Not only does it provide more time for both technical and non-technical subject matter, but it should also permit the student to determine his special niche and develop his own particular talents. It should make it possible to provide, where needed, greater depth in the physical sciences, in the engineering sciences, and in mathematics. It should permit the opportunity for more effective integration of the social sciences and the humanities into engineering programs. And at the same time it should help satisfy the widely felt need for increased emphasis on analysis, synthesis, and design at all levels. And by including a year of graduate study, it should enable the student to acquire a pattern and habit of self-development that will stand him in good stead throughout his engineering career.

### *Accreditation*

The purpose of accreditation is to advance the quality and effectiveness of engineering curricula and to make sure that they meet appropriate minimum standards of excellence, but not to strait-jacket the educational programs—not to enforce a rigid pattern of conformity.

* The need for supporting personnel, especially programmers, technicians, etc., would be greatly served if a comprehensive national study were undertaken which would involve representation from technical institutes, community colleges, engineering colleges, as well as the professional organizations concerned with technician, engineering and scientific personnel.

Although there is considerable difference of opinion regarding the extent to which engineering accreditation in the past has encouraged experimentation and innovation, there is a general consensus that accreditation procedures and policy *should* encourage innovation and at the same time maintain high standards of quality. Therefore, a flexible program for the immediate future is favored—one that would provide for accreditation either at the bachelor's or master's level, or both; either by special or general field (C. E., E. E., etc., or Engineering); and either of a curriculum, such as those mentioned, or, if the institution prefers, of an entire college or academic unit. The degree of attainment of the stated goals of the curriculum or of the academic unit should be the primary basis for accreditation.

As for the possibility of accreditation of advanced engineering programs—that is, programs leading to degrees beyond those recognized in the basic engineering program—it is recommended that consideration of such a practice be postponed until such time as a clearer need develops.

### Advanced Engineering Education

In recent years graduate engineering enrollment has increased faster than undergraduate enrollment. There is no reason to expect that as the level of basic engineering education is raised there will be any abatement of the demand for advanced engineering study on an optional basis leading to degrees beyond that prescribed as basic. For most students, the master's degree will be part of the basic program, commencing at the freshman level and extending over five years. But for others, it will be a stepping stone to the doctorate. Indeed, it is estimated that by 1978, about one engineer in seven will go on to a doctorate.

A significant finding of the Goals Study is that engineers with advanced degrees are in all engineering functions, including design and management, so it should not be assumed that those seeking advanced degrees are interested only in teaching and research. It is clear that increased provision should be made for advanced education of high quality to prepare students for all of the engineering functions, and that existing programs should be improved and broadened. There is a scarcity of experimental programs at the master's level, where more work is needed in the development of group design projects, use of the case method, etc. In addition, consideration should be given to the opportunities provided by intermediate degrees (for example, the Engineer degree) for experimentation with new graduate programs. Doctoral study should certainly be regarded more broadly by educators and engineers alike as preparation for the highest levels of creative leadership in all areas of engineering practice, and efforts should be made to expand the opportunities for increasing numbers of engineering students who will be seeking the doctor's degree.

### Faculty

Next to the student body, the faculty is the most important factor in assuring the success of any engineering educational program. Technical competence, scientific understanding, creative ability and humanistic wisdom are required, the third especially in advanced engineering programs. There seems to be a general recognition of the need for closer association of the engineering faculty with their academic colleagues in liberal studies as well as in physical sciences, and also with practicing engineers of proved ability and vision. Thus may the faculty help give both realistic and imaginative insight into contemporary problems and an inspiration to solve them—especially those of urgent importance.

Programs should be developed to insure continued upgrading of faculty, through sabbatical leaves, summer institutes, creative research, and consulting and industrial experience. Faculty should be encouraged to take advantage of the educational opportunities for continued development offered by the Ford Foundation, The National Science Foundation, the National Aeronautics and Space Administration, and other programs designed for this purpose. Education to the doctoral level should continue to be regarded as the expected preparation for teaching.

### Research

It is vital that there be the fullest possible integration of research with the educational purpose of engineering colleges. Support of faculty and student research—both from the federal government and from other sources—has been climbing steadily in recent years, and it is important that this increase continue as the numbers of graduate students grow. If the estimated number of doctorates is to be produced, the level of research support to engineering graduate schools should increase from its 1963 level of $160 million to as much as $700 million or more by 1978. It is recommended that industry increase substantially its support of research in engineering schools as part of its program of general educational support, using existing or new arrangements for grants or contracts.

### Part-Time and Off-Campus Advanced Study

When the local situation justifies it, engineering colleges should establish and maintain high-quality part-time advanced degree programs for on-campus study by employees of nearby industry and government. Moreover, serious attention should be given to the development of new techniques and arrangements for extending advanced engineering education to persons employed so far from the campus as to make commuting difficult.

### Continuing Studies

It is recommended that engineering schools recognize more fully the place of continuing studies as a distinct category in the spectrum of engineering education, and that wherever possible they provide increased leadership in the planning and offering of continuing studies as part of normal institutional activity. It is also recommended that engineering schools cooperate to a much greater extent with industry, government, and the engineering societies in such programs, in order to achieve maximum benefit for the student and optimum utilization of teaching resources.

# Part B. The Engineer In Future Society

## 1. TECHNOLOGICAL NEEDS OF THE FUTURE

THE WESTERN WORLD, and especially the United States, has often been characterized as a "technological society." This phrase reflects the great impact that engineering, as the strong right arm of science, has had upon western society. In almost every aspect of human enterprise the activities of the engineer are playing an increasingly important role and these activities will continue to have far-reaching social, economic, and political consequences in the world of the future.

A recent report by personnel of the Rand Corporation attempts to depict the world of the future at several points in time. Using the views of experts in six major areas of human activity, an effort was made to visualize the world of 1984 and of 2000:

### *The World of 1984*

If we abstract the most significant items from the forecasts of all six panels, the following picture emerges as the state of the world as of 1984:

The population of the world will have increased by 40% from its present size to 4.3 billion—that is, provided no third world war will have taken place before then.

To provide the increased quantities of goods needed, agriculture will be aided by automation and by the availability of desalinated sea water.

Effective fertility control will be practiced, with the result that the birth rate will continue to drop.

In the field of medicine, transplantation of natural organs and implantation of artificial (plastic and electronic) organs will be common practice. The use of personality-control drugs will be widespread and widely accepted.

Sophisticated teaching machines will be in general use. Automated libraries which look up and reproduce relevant material will greatly aid research. World-wide communication will be enhanced by a universal satellite relay system and by automatic translating machines. Automation will span the gamut from many service operations to some types of decision making at the management level.

In space, a permanent lunar base will have been established. Manned Mars and Venus fly-bys will have been accomplished. Deep-space laboratories will be in operation. Propulsion by solid-core nuclear-reactor and ionic engines will be available.

In the military arena, ground warfare will be modified by rapid mobility and a highly automated tactical capability, aided by the availability of a large spectrum of weapons, ranging from nonlethal biological devices and light-weight rocket-type personnel armament to small tactical nuclear bombs and directed-energy weapons of various kinds. Ground-launched anti-ICBM missiles will have become quite effective. Anti-submarine warfare techniques will have advanced greatly, but improved, deep diving, hard-to-detect submarines will present new problems (Ref. B-1).

### *The World of 2000*

When we continue our projection to the year 2000, the following major additional features emerge as descriptive of the world at that time, judging from the forecasts of the six panels:

The population size will be up to about 5.1 billion (65% more than 1963).

New food sources will have been opened up through large-scale ocean farming and the fabrication of synthetic protein.

Controlled thermonuclear power will be a source of new energy. New mineral raw materials will be derived from the oceans. Regional weather control will be past the experimental stage.

General immunization against bacterial and viral diseases will be available. Primitive forms of artificial life will have been generated in the laboratory. The correction of hereditary defects through molecular engineering will be possible.

Automation will have advanced further, from many menial robot services to sophisticated, high-IQ machines. A universal language will have evolved through automated communication.

On the Moon, mining and manufacturing of propellant materials will be in progress. Men will have landed on Mars, and permanent unmanned research stations will have been established there, while on Earth commercial global ballistic transport will have been instituted.

Weather manipulation for military purposes will be possible. Effective anti-ICBM defenses in the form of air-launched missiles and directed energy beams will have been developed (Ref. B-2).

These forecasts suggest (1) that large scale systems will be created for the development, control, and use of our natural resources, and (2) that development will continue (a) of automated manufacturing industries, (b) of synthetic foods to meet the needs of an expanding world population, (c) of rapid transportation systems for land, sea, and air, (d) of space programs and design of more efficient and humane military defense systems, and (e) of bio-social systems having to do not only with medical advances, housing, community development, and pollution control but also with their coordination into large scale social systems such as vast metropolitan complexes that will utilize technological advances more effectively.

Each of these developments contains the promise of greater well-being for the people of the United States and the world. However, each change may also create new and probably unanticipated problems that will have to be solved in part by the engineer.

## 2. ENGINEERING EDUCATION TO MEET FUTURE NEEDS

It is within the context of this large picture that the Goals Study has attempted to point the way toward the development of engineering education in the decades ahead. At best, crystal-ball gazing is a risky business. Yet a careful examination of the direction in which engineering education has been moving in recent years and a judicious consideration of the opinions of educators, practicing engineers, and employers regarding the needs and requirements of the future can serve as a reasonable basis for establishing practical guidelines toward ultimate goals.

It should be emphasized that the Goals Committee has in no sense interpreted its charge as that of arriving at a consensus—of counting the pros and cons on the many controversial issues to be faced and then recording a series of majority opinions. Rather the aim has been to evaluate current programs, practices and proposals in the light of their applicability ten or twenty years hence, and, on the basis of considered judgment, to propose a few broad goals which appear to be of paramount importance in determining the direction which engineering education must take.

From the mass of material collected and digested by the Goals Committee during the past five years of intensive survey and analysis, the following *observations* stand out as being of continuing significance:

(a) Society's needs in the decades ahead will call for engineering talent on a scale never before seen in the United States or elsewhere. As a consequence of these needs the opportunities for engineering education must be greatly expanded in order to attract and educate larger numbers of people at all levels of competence.

(b) The engineer of the future will be called upon to play an increasing role in the solution of complex social problems and as a consequence, engineering education must impart a thorough knowledge of the many non-technical aspects of modern life which interact significantly with the technical problems, which are the engineer's major concern. It seems equally important that engineering education should be made sufficiently flexible to provide an opportunity for the optimum development of a wider variety of individual activities, aptitudes, and interests.

(c) In view of the rapid advance of knowledge and of the rapid growth in complexity of technological endeavor, the engineer of the future will need greater technical competence and as a consequence of this need, engineering educators must provide an improved technical education as basic preparation for the majority of tomorrow's practicing engineers.

# 3. THE NEED FOR MORE ENGINEERS

A National Science Foundation Study published in 1963 sets forth the requirements and supply of scientists, engineers and technicians in the early 1960's, as well as anticipated future supplies and demands based on the assumption of high levels of economic activity, continued technological advances, increases in the complexity of industrial processes and growth in research and development. Table B-1, reproduced from this document, shows the 1960 supply and the projected 1970 demand by type of employment (Ref. B-3). Scientists would have to increase 72.9%, technicians 67.3%, and engineers would have to increase from 822,000 to 1,374,700 or 67.2% in the 10-year period to meet the projected demand.

The report of this study expresses concern because (1) the projected demand for over 700,000 new engineers (including replacements) will exceed the expected supply of 450,000 by over 250,000, and (2) approximately one third of the anticipated demand will have to be met by non-engineering graduates. The report suggests the need "to attract more students into engineering," and says: "Additional provisions—making certain that the necessary university facilities, equipment and staff are available and that young people have the secondary school background, sufficient motivation, and the financial ability to attend college will require the combined efforts not only of college and university administrators and of employees, but also government, professional societies and the general public." The report further examines the implications of increased graduate education and attrition especially among the highly talented engineering students. It also points out the necessity for expanded training programs in industry and government, more efficient use of technicians and better utilization of engineers and scientists.

Another study, prepared in 1966 by the Engineering Manpower Commission of the Engineers Joint Council, predicts demand for 830,000 new engineers in the period 1965-1976 (Ref. B-4). This report also indicates that industry and government anticipate employing an increased proportion of advanced degree engineers and an increased ratio of technicians to engineers. This report also expressed concern over the supply of engineers in the next decade, in view of the relatively stable output of engineering schools at the bachelor's level.

The survey of engineering graduates in industry and government by the Goals Committee got the opinions of engineers about the adequacy of present personnel and the relative needs in the future. Figure B-1 shows that opinion was about equally divided on present adequacy, while the overwhelming majority foresaw increased need at all degree levels during the next decade.

The increasing need for engineering personnel is part of the long-range trend in the make-up of the United States labor force since the turn of the century and there is every reason to expect a continuation of this trend.

Table B-2 gives the ratio of total labor force to engineers in the United States from 1890 until 1960. It declined from 825 workers per engineer in 1890 to 218 in 1930 and 75 in 1960 when approximately one in 50 of the total male labor force was employed as an engineer. Figure B-2 shows the growth trend of engineers in relation to the total force between 1930 and 1963.

It is questionable whether, even with a continuation of this trend, future demands for engineering personnel in the United States could be met.

But the needs for engineering talent extend beyond national boundaries. In addition to the needs of American industry and government, it must be kept in mind that the demand for engineers will be rising rapidly elsewhere in the world, and that part of this demand will probably be met by American personnel. Table B-3 shows the great variation in the proportion of engineers and scientists in the populations of various countries. As may be seen, Sweden, the United States, and the USSR rank relatively high, whereas in Kenya, China, and Greece, relatively lower proportions of the total population are engaged in engineering and scientific

TABLE B-1

ENGINEERS, SCIENTISTS, AND TECHNICIANS BY INDUSTRY, 1960 EMPLOYMENT AND PROJECTED 1970 REQUIREMENTS

| | Engineers | | Scientists | | Technicians | |
|---|---|---|---|---|---|---|
| Type of Employment | 1960 employment | 1970 requirements | 1960 employment | 1970 requirements | 1960 employment | 1970 requirements |
| Mining | 19,100 | 27,900 | 12,400 | 13,000 | 11,600 | 14,000 |
| Construction | 52,700 | 102,000 | 2,400 | 4,600 | 32,700 | 63,300 |
| Manufacturing | 472,800 | 823,000 | 140,700 | 241,100 | 420,200 | 749,300 |
| Transportation | 58,700 | 75,900 | 2,800 | 3,500 | 57,900 | 73,400 |
| Government | 109,400 | 147,100 | 60,700 | 95,000 | 138,100 | 191,200 |
| College and university | 27,000 | 52,000 | 98,100 | 188,000 | 10,000 | 20,000 |
| Other industry | 82,100 | 146,000 | 18,200 | 33,100 | 105,600 | 179,100 |
| TOTAL | 822,000 | 1,374,700 | 335,300 | 579,600 | 775,100 | 1,296,700 |
| Percent of increase needed | 67.2 | | 72.9 | | 67.3 | |

Reference: *Scientists, Engineers, and Technicians in the 1960's, Requirements and Supply.* National Science Foundation, NSF 63-34 (Washington, D.C., 1963), pp. 34-6.

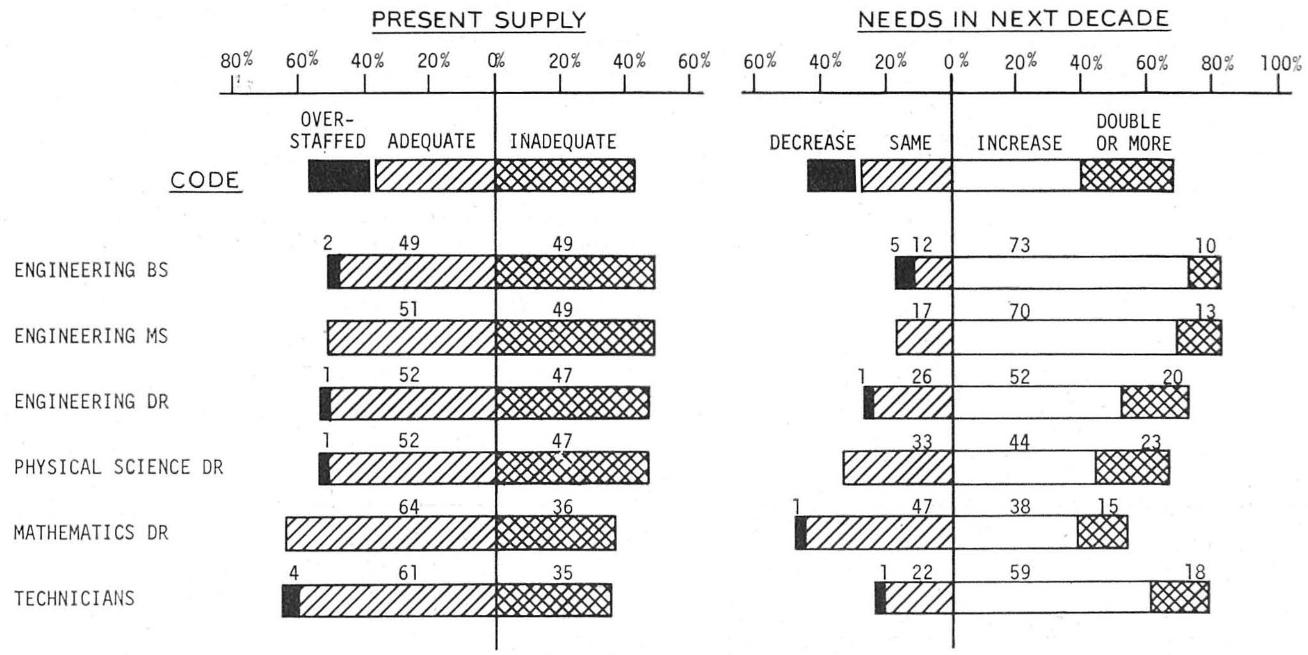



Figure B-1. Engineers' opinions on adequacy of present (1964) personnel and relative needs during the next decade.

fields. It is apparent that as the under-developed countries become more industrialized, the need for technical personnel will increase.

Thus, it seems clear that American engineering educators must accept the responsibility of substantially increasing the production of qualified engineers to meet the needs of society.

*Therefore, it is recommended that the engineering profession and engineering educators make every effort to attract an increasing number of students to engineering at both the undergraduate and graduate level by providing potential students with stimulating and accurate information regarding engineering as a career and by encouraging the expansion of existing opportunities to study engineering and by the erection of new facilities which will enable a greater number of students to study engineering in the future. Efforts should also be made to retain students in engineering curricula.*

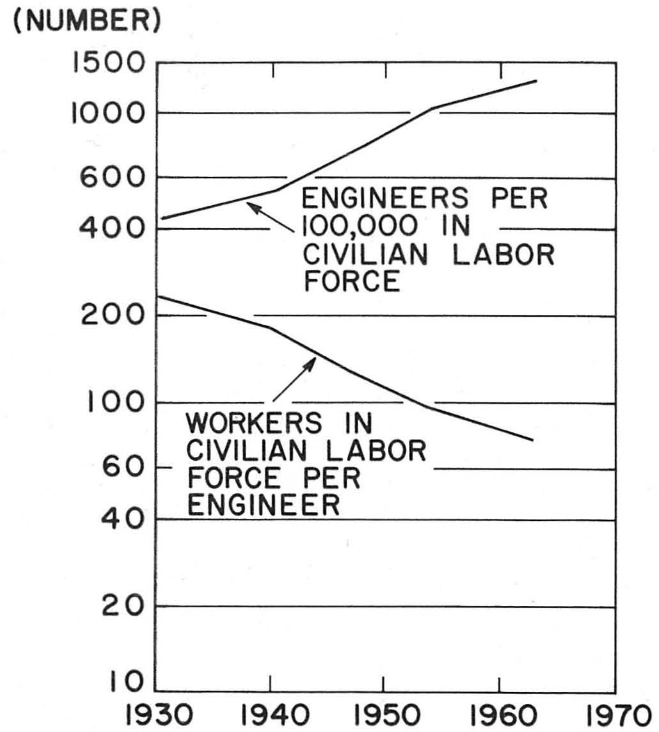



Figure B-2. Growth trend of engineers in relation to labor force, selected years, 1930-63.
Reference: National Science Foundation, Scientific and Technical Manpower Resources, NSF 64-28, Washington, D. C., pp. 13-14.

TABLE B-2
GROWTH OF LABOR FORCE AND ENGINEERS FOR CENSUS YEARS

| Year | Total (Millions) | Engineers | Ratio Labor Force: Engr. |
|---|---|---|---|
| 1890 | 23.3[1] | 28,238[5] | 825 |
| 1900 | 29.1[1] | 43,238[5] | 673 |
| 1910 | 37.4[1] | 88,755[5] | 421 |
| 1920 | 42.4[1] | 136,121[5] | 311 |
| 1930 | 47.4[2] | 217,845 | 218 |
| 1940 | 44.9[3] | 272,145 | 165 |
| 1950 | 56.2[3] | 520,856 | 108 |
| 1960 | 64.6[4] | 860,949 | 75 |

[1] Gainful workers 10 years or over
[2] Labor force, 14 years and over
[3] Civilian employment labor force, 14 years and over
[4] Total employed
[5] Includes Engineers and Surveyors

References:
Blank and Stigler, "The Demand and Supply for Scientific Personnel," 1957, National Bureau of Economic Research, Table B-1.
1960 U. S. Census and Summary, Detailed Characteristics, Table 202.

TABLE B-3

COUNTRIES RANKED BY PROPORTION OF ENGINEERS AND SCIENTISTS IN THEIR POPULATION

| | Engineers and scientists per 10,000 population | Per cent of those in higher education enrolled in scientific fields | Per cent of 20-24 year olds in college | Per cent of population in agriculture |
|---|---|---|---|---|
| Kenya | 0.9 | 21.9 | 0.05 | 88 |
| India | 2.4 | 27.3 | 2.2 | 71 |
| China (Mainland) | 3.1 | 55.7 | 1.0 | 69 |
| Greece | 13.7 | 24.5 | 3.5 | 48 |
| United Kingdom | 33.2 | 22.1 | 7.9 | 5 |
| USSR | 48.1 | 45.3 | 11.8 | 50 |
| United States | 61.7 | 22.7 | 33.2 | 12 |
| Sweden | 63.5 | 30.4 | 8.1 | 20 |

Reference: Harbison, Frederick and Charles A. Myers, *Education, Manpower, and Economic Growth*, McGraw-Hill Book Company (New York, 1964), pp. 45-48.

*It is recommended that the continued and increased development of technician programs be encouraged and that a national study of technician education be undertaken which would involve representation from technical institutes, community colleges, engineering colleges, as well as the professional organizations concerned with technician, engineering and scientific personnel.*

The rapid development of two-, three-, and four-year technician programs would seem to warrant such a study at this time. These developments have received consideration in Appendix IV.*

# 4. THE NEED FOR BREADTH IN ENGINEERING EDUCATION

In the past, general subjects were included in undergraduate and graduate engineering curricula for a two-fold purpose: (1) to provide a foundation notably in mathematics, physics and chemistry, for the professional engineering courses, and (2) to provide content in the humanities, social sciences and communications so that graduates could assume their role as college-educated citizens in our society.

Mathematics and the physical sciences have continued as ingredients of engineering education, but the needs for general education now include knowledge of the life sciences, the social sciences and the humanities as necessary qualifications for engineers' performance as *working members* of society, as well as broadly educated citizens. The rapid development of interdisciplinary activities makes it paramount that future engineering graduates have a broad enough education to enable them to cope not only with physical forces but biological and social forces as well so that they may make contributions with other colleagues to the solution of the still dimly seen problems of tomorrow.

*A proposal of the Technical Institute Administrative Council of ASEE for a comprehensive study of the goals of engineering technology education is now under consideration by funding agencies.

Responding to inquiries about the future role of engineering graduates, educators from 156 institutions, as may be noted in Figures B-3 and B-4, were more likely to anticipate an increase in the social than in the technical role of engineers in the decade ahead. It seems clear, then, that educational programs must be designed to help engineers meet the challenge of this new responsibility.

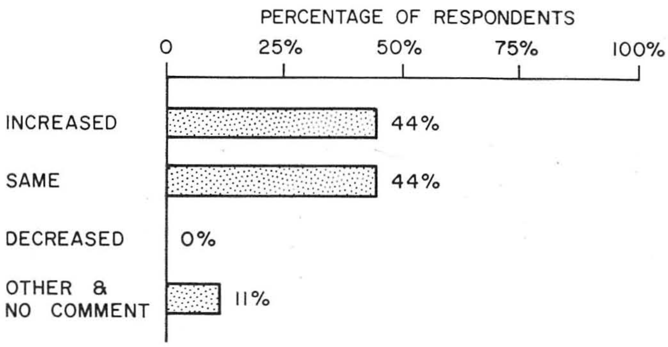



Figure B-3. Educators' opinions on technical role of engineering graduates in the next decade.

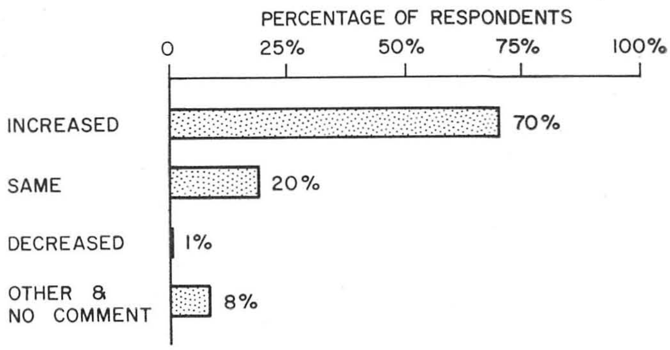



Figure B-4. Educators' opinions on the social role of engineering graduates in the next decade.

Non-technical activities in the day to day life of engineering graduates share importance with technical activities. Engineering graduates report the use of English composition, speech and economics as frequently as the use of algebra, engineering design and properties of materials. Similarly letter and memo writing, supervision, and oral and written reporting were among the most frequently reported activities of engineering graduates (Ref. B-5). Similar findings have also been reported in other surveys of engineering graduates, one of the most significant being the study of the ASEE Feedback Committee entitled "Education in Industry," a study by Joint ECAC-RWI Feedback Committee, ASEE, 1965, a joint undertaking of the Relations With Industry Division and the Engineering College Administrative Council. These findings stress the dual importance of liberal and technical content of engineering education.

Additional support for the viewpoint that there is an important need for breadth in the education of future engineers is found in the opinions of practicing engineers surveyed. When questioned, about one-half of the engineering graduates indicated that their undergraduate experience did not provide enough liberal or general education (Ref. B-6). A similar view was noted in the comments of engineering managers and personnel representatives who were queried regarding the strengths and weaknesses of recent and earlier graduates. For example, 60% of the managers felt earlier graduates were "too weak" and 35% felt that recent graduates were "too weak" in liberal or general education (Ref. B-7).

The following *observations* are presented: (a) Engineering education and the engineering profession must recognize the integral role of general and professional education at both undergraduate and graduate levels. (b) New interdisciplinary activities will continue to emerge not only within engineering and the natural sciences, but also within the life sciences, the social sciences and the humanities during the coming decade. These developments will create new challenges for the future. (c) Strides made in recent years in broadening and liberalizing the education of engineering students should be continued and extended during the next decade.

*Therefore, it is recommended that (a) the engineering student should be sufficiently exposed to the new facts and theories offered by the social sciences to help him understand the large social problems of his time; (b) he should be persuaded in college to set a course of life-long study in this area; (c) he should be impressed with the importance of his role in the ultimate solution of these problems; (d) he should understand and appreciate the vital mutual influences which have been operating since the industrial revolution between technology on the one side and the more slowly changing institutions of society on the other; (e) the youthful idealist should be persuaded that engineering offers him a field of opportunity for the exercise of his enthusiasms and fulfillment of his highest goals for humanity.*

*It is also recommended that the appropriate organizations launch a nation-wide investigation of the education of the engineer in communications, the humanities and social sciences—a comprehensive study in depth of all the forces and activities that help or hinder this educational enterprise in the life of the student—from high school diploma to college degree. Such a study might reveal that the problem of providing adequate work in humanities and social science is not peculiar to engineering; that it arises wherever a student is preparing to become an expert in a specialized field.*

# 5. THE NEED FOR ENGINEERS EDUCATED AT HIGHER LEVELS

We now address ourselves to another and perhaps the most important and controversial matter, *the need for a greater proportion of engineers educated at higher levels and the corresponding need for expanded educational opportunities.* We will show that the students have been moving rapidly in that direction, that in some fields virtually all engineering graduates have been going beyond the bachelor's degree and that in others this is rapidly becoming the case. In addition we will note the views of engineering graduates and attitudes of industry and government on graduate work.

### *The Students*

As is shown in Part D of this report (See Figure D-2) baccalaureate degrees in engineering have been increasing at about the same rate as all baccalaureate degrees in the United States (5%/yr.) since the turn of the century. However, advanced degrees in engineering have been increasing faster than the national average (11% vs. 7% at the master's level, 12% vs. 6% at the doctor's level). In part, this has been due to the fact that until recent years very few engineers except those going into teaching went on to graduate school. However, interest in graduate work in engineering has changed markedly since World War II and the increase has been especially striking during the past decade. There are many reasons for this increase, but perhaps the most important factors are (1) the increasing importance attached to formal education in contemporary society, (2) the affluence of our society which permits a greater proportion of students to continue their education, (3) the increasing availability of graduate fellowships in colleges and universities, (4) expanded opportunities to pursue graduate work on a part-time basis, and (5) perhaps most important, the changing aspirations of students, especially the most talented.

Engineering has, over the past decade, attracted about 10% of the male college population and awarded about 12% of the bachelor's degrees received by males (Ref. B-8), but has attracted an even larger percentage of the most talented students. For example, in the *Project Talent 1961 Study* over one fourth of the male high school seniors in the upper 2% of their aptitude battery and over one-fourth of the male seniors in the upper 10% of their aptitude battery were studying engineering the following year. It was also noted that 21% of all male high school students in the study and 57% of those in the upper 10% of the ability spectrum planned to do graduate work (Ref. B-9).

Similar results may be observed in the studies of National Merit Scholars in which the proportion of male merit scholars studying engineering has varied between 34% and 18% (Ref. B-10) during the past decade. Recent studies of these highly talented students indicate that 95% of the male scholars plan to do graduate work and 72% expect to complete work for the doctor's degree (Ref. B-11).

Additional support for the changing educational goals of college students is presented in a 1962 national study of graduating college seniors entitled *Great Aspirations.* This study indicated that "a bachelor's degree recipient is more likely to anticipate post-graduate study than a high school student is to anticipate college" (Ref. B-12). This study which was based on 1962 college graduates, indicated that 78% of the 1962 class planned to do graduate work (33% the next year and 45% later). The same percentages were found to be true for engineering graduates.

*Engineering Graduates*

However, as may be noted in Table B-4, the percentage of engineering majors planning immediate graduate work was somewhat lower than that in other fields which normally attract a similarly high proportion of talented college students, e.g., biological sciences, physical sciences, social sciences, and humanities. These data suggest that although engineering graduates are as likely as any to view graduate work as an eventual goal, they are less likely than their colleagues in other fields to plan graduate work immediately following graduation.

TABLE B-4

MALE 1962 COLLEGE GRADUATES PLANNING GRADUATE WORK NEXT YEAR

| Undergraduate Major | Scholastic Rank: Top Fifth | Above Average | Bottom Half |
|---|---|---|---|
| Biological sciences | 94% | 77% | 52% |
| Physical sciences | 84 | 61 | 31 |
| Social sciences | 72 | 52 | 35 |
| Humanities | 75 | 55 | 37 |
| Other Professions | 65 | 41 | 24 |
| ENGINEERING | 62 | 36 | 18 |
| Education | 44 | 40 | 23 |
| Business | 38 | 23 | 12 |

The *Great Aspirations* study also provided some comparative data on the differences within engineering by field of specialization. For many years a higher percentage of chemical than of electrical, civil or mechanical engineering graduates have gone on for advanced degrees. However, data in Table B-5 suggest that graduate work is viewed as a *potential* goal by a higher percentage of electrical and mechanical than of chemical engineers today, although more chemical engineers planned on *immediate* graduate work.

TABLE B-5

1962 COLLEGE GRADUATES BY ENGINEERING FIELD PLANNING TO GO ON TO GRADUATE SCHOOL

| FIELD | GRADUATE FIELD: Total | Next Year | Later | Never | (N) |
|---|---|---|---|---|---|
| Electrical Engineering | 90% | 40% | 50% | 10% | 89* |
| Engineering Total | 77 | 32 | 45 | 23 | 4,393 |
| Mech. Engineering | 73 | 14 | 59 | 27 | 37* |
| Chemical Engineering | 67 | 50 | 17 | 33 | 18* |
| Civil Engineering | 60 | 22 | 38 | 40 | 45* |

* Based on a Representative Sub-Sample
Source: Davis, J., *Great Aspirations, Vol. 1*
National Opinion Research Center, Chicago, 1963, pp. 307-309

In some fields, notably nuclear engineering and sanitary engineering, virtually all graduates in recent years have received the master's or higher degree. This is rapidly becoming the case in aeronautical engineering, metallurgical engineering, engineering science and materials (Ref. B-13).

But interest in graduate study is not confined to students and recent graduates. When queried as to whether or not they would do graduate work if they had their education to do over, 85% of practicing engineers surveyed by the Goals Study said "yes" (Fig. B-5).

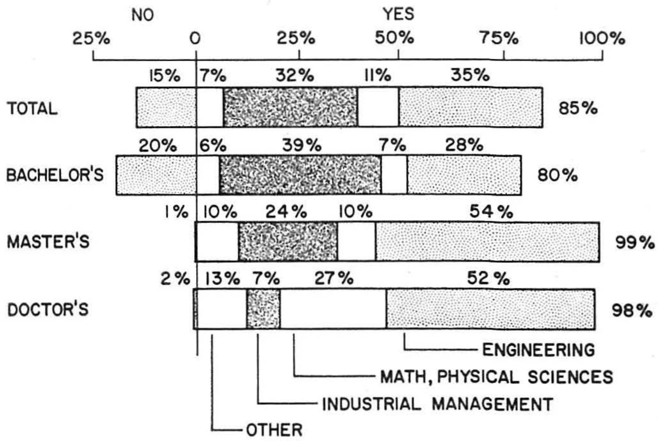



Figure B-5. Choice of graduate curriculum. (Percentage of practicing engineers who selected various responses when asked, "If you had your education to do over again, would you go on to graduate work?")

The types of programs preferred varied considerably depending upon the respective degree level, with bachelor's degree graduates more likely than advanced degree graduates to prefer management-oriented study and less likely to prefer mathematics and physical sciences.

Additional evidence was obtained in the pre-test of the Industry-Government Survey in which the question was posed:

*"In your opinion, what is the minimum and optimum level of education necessary for your present position?"*

| RESPONSE | PER CENT OF REPLIES*: Minimum | Optimal |
|---|---|---|
| High School or less | 2% | 0% |
| About two years or college | 18% | 2% |
| Bachelor's degree | 75% | 33% |
| Master's degree | 4% | 53% |
| Doctor's degree | 1% | 12% |

Although the majority (80%) felt a bachelor's degree or higher was the *minimum* level, 65% indicated that the master's degree or higher was *optimal.*

There is considerable evidence, therefore, that both college students and graduates are considering graduate work in increasing numbers and proportions, and it appears that the views of engineering graduates are consistent with this total national movement.

Other evidence supporting the importance of graduate work in engineering is given in Part D of this report.

*Industry, Government and Education*

There is a general consensus on the part of representatives of industry and government that the proportion of engineers with graduate education will increase in the future. Some of the most recent and comprehensive data on this aspect of engineering manpower were collected as part of the biennial survey of the demand for engineers and technicians conducted by the Engineering Manpower Commission (Ref. B-4). The report indicated an overall increase of 36.3% in new "hires" at the bachelor's level between 1964 and 1965 and an additional 8.7% increase between 1965 and 1966; however, the master's degree increases were 55.5% and 9.5% respectively and the

* BS-MS sample only.

doctoral new "hires" 26.3% and 29.1%. It is interesting to note that the total increase in new "hires" for the two year period of 1964-1966 in terms of 1964 "hires" was 48% for the bachelor's degree, 71% for the master's degree and 89% for the doctor's degree. These data suggest that recent hiring practices by industry and government have already reflected the trend toward higher degree levels.

It is, therefore, understandable that when industrial and governmental and educational organizations were queried by the Engineering Manpower Commission the overwhelming majority anticipated an increase at the master's degree and the doctor's degree levels and a decline in the proportion of engineers with bachelor's degree or no degree. Table B-6 summarizes the results.

### *International Comparisons*

Although international comparisons are always difficult and sometimes invidious, it appears that at least twelve of the eighteen national educational plans of the countries of Western Europe displayed in a EUSEC report (1960) (Ref. B-14) show a longer period of education than the equivalent of a four-year U. S. bachelor's degree program as preparation for entering the engineering profession. (The countries with longer programs are Belgium, Denmark, Finland, France, West Germany, Greece, Iceland, Italy, Norway, Spain, Sweden and Turkey. The countries with programs of approximately equal length are Austria, Ireland, Switzerland, and the Netherlands. The United Kingdom appears to have programs of lesser length. The diagram for Luxemburg's program does not indicate its length.)

### *Summary*

Throughout this section we have observed that students, especially the highly and most talented students, have been anticipating graduate studies in increasing proportions. Since engineering in the past has attracted a significant proportion of these highly talented students and presumably will continue to attract them in the future, engineering education and the engineering profession should recognize the increasing aspirations of future engineering students and plan to assimilate a greater proportion of advanced degree engineering students in the future. Although the majority of the practicing engineers in industry and government agree that the bachelor's degree is the minimum educational level required for their present work, the majority agree that the master's degree would be optimal and the overwhelming majority would go on to graduate work if they had it to do over again. In addition, recent hiring practices of industry, government and education as well as anticipated future policy indicate that a greater proportion of new engineering "hires" in the next decade will have advanced degrees.

*Therefore, it is recommended that the engineering profession and engineering educators recognize the inevitability of increased graduate level education in the future and take whatever steps are necessary to provide the opportunity for at least one year of graduate study for the majority of those who will complete their undergraduate education during the coming decade.*

# 6. BASIC AND ADVANCED ENGINEERING EDUCATION

In considering the above recommendation for an increase in the educational level of engineering graduates, it is suggested that a new *professional* terminology be introduced, namely, the phrases, "basic engineering education" and "advanced engineering education." This should be distinguished from *academic* terminology, which is incorporated in the terms "undergraduate education" and "graduate education." For the purposes of

**TABLE B-6**
**FUTURE TRENDS**
**How Respondents Believe The Proportion of Engineers Whose Highest Degree Is as Indicated Will Change Over The Next Decade**

| | BACHELORS | | | MASTERS | | | DOCTORS | | | NO DEGREE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Incr. | Same | Decr. | Incr. | Same | Decr. | Incr. | Same | Decr. | Incr. | Same | Decr. |
| All Respondents | 15 | 25 | 60 | 86 | 12 | 2 | 67 | 32 | 2 | 5 | 20 | 75 |
| All Industry | 15 | 25 | 60 | 91 | 9 | 0 | 70 | 29 | 1 | 2 | 21 | 77 |
| Aerospace | 20 | 45 | 35 | 96 | 4 | 0 | 95 | 5 | 0 | 1 | 0 | 99 |
| Chemical | 1 | 1 | 98 | 99 | 1 | 0 | 15 | 85 | 0 | 0 | 79 | 21 |
| Construction | 13 | 4 | 73 | 98 | 2 | 0 | 78 | 22 | 0 | 4 | 1 | 95 |
| Consulting | 14 | 35 | 51 | 76 | 24 | 0 | 27 | 71 | 2 | 7 | 32 | 61 |
| Electronics | 4 | 63 | 33 | 83 | 17 | 0 | 23 | 77 | 0 | 3 | 22 | 75 |
| Machinery | 27 | 22 | 51 | 67 | 33 | 0 | 29 | 52 | 19 | 9 | 26 | 65 |
| Metals | 8 | 1 | 91 | 93 | 7 | 0 | 91 | 7 | 2 | 2 | 5 | 93 |
| Miscellaneous Mfg. | 4 | 3 | 93 | 96 | 4 | 0 | 95 | 5 | 0 | 0 | 2 | 98 |
| Petroleum | 28 | 0 | 72 | 99 | 1 | 0 | 49 | 51 | 0 | 0 | 80 | 20 |
| Research & Development | 0 | 4 | 96 | 97 | 3 | 0 | 97 | 3 | 0 | 0 | 10 | 90 |
| Transportation Services | 29 | 32 | 39 | 59 | 41 | 0 | 0 | 93 | 7 | 0 | 1 | 99 |
| Utilities | 30 | 36 | 34 | 69 | 31 | 0 | 28 | 66 | 6 | 9 | 27 | 64 |
| All Government | 17 | 28 | 55 | 79 | 17 | 4 | 37 | 59 | 4 | 23 | 12 | 65 |
| Federal Government | 3 | 39 | 58 | 85 | 12 | 3 | 43 | 57 | 0 | 3 | 14 | 83 |
| State Government | 36 | 10 | 54 | 77 | 18 | 5 | 33 | 54 | 13 | 50 | 9 | 41 |
| Local Government | 16 | 54 | 30 | 48 | 48 | 4 | 0 | 87 | 13 | 20 | 15 | 65 |
| Education | 1 | 13 | 86 | 18 | 47 | 35 | 99 | 1 | 0 | 5 | 34 | 61 |

Source: Engineering Manpower Commission: Demand for Engineers and Engineering Technicians 1966, EJC further discussion in this report the following terms will be used:

(a) *Undergraduate education: educational activities in which students pursue academic work for credit toward a technician's certificate or bachelor's degree.*

(b) *Graduate education: educational activities in which students pursue academic work for credit toward post-baccalaureate degrees.* This includes at most institutions the master's degree and the doctor's degree, and in a few institutions, the engineer degree.

(c) *Basic education: the education ideally expected for entry into a profession.* In some professions, for example, medicine, this would be four years of medical school education after the bachelor's degree. In architecture and pharmacy this has normally been 5 years of work at the undergraduate level. In engineering this has been the bachelor's degree in the past in most fields, although in some fields, notably sanitary engineering and nuclear engineering, this has been the master's degree and in engineering teaching it has been in recent years the doctor's degree.

(d) *Advanced education: education pursued by the student following his basic education. It is undertaken optionally.* In medicine, this would run from 2 to 7 years depending on the specialty.

These four concepts are shown schematically in Figure B-6 for engineering education. In the past, basic engineering education in most fields was synonymous with undergraduate education, but the Goals study has shown that this view is rapidly changing.

*The Goals Committee recommends, therefore, that during the next decade basic engineering education be extended to include at least one year of graduate level education leading to the master's degree.*

## 7. SUMMARY

In this part of the Goals Report we have discussed the increasing complexity of the technological needs of the future. We have suggested that to meet the challenges of the future will require engineering, scientific and technological manpower on a scale never before seen in the United States or elsewhere. It seems evident that the engineer of the future will not only have to be educated in greater breadth but in greater depth as well. To accomplish these needs it is suggested that there be: (a) expanded opportunities for the study of engineering, (b) recruitment into engineering of a larger share of the highly talented youth in our society, (c) the design of curricula to provide greater breadth and flexibility, (d) the extension of basic engineering education to include at least one year of graduate level education.

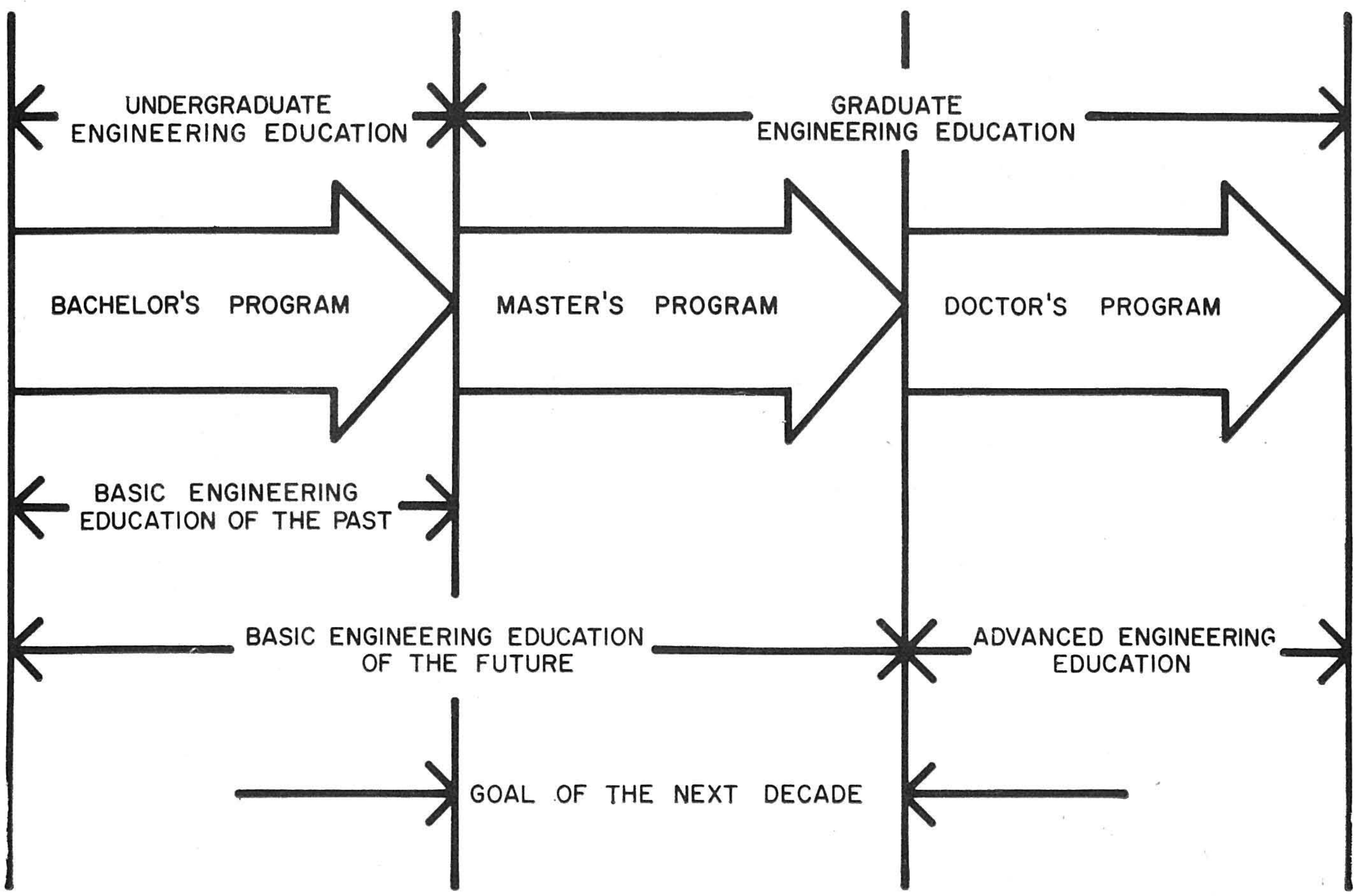



Figure B-6. Undergraduate and graduate engineering education versus basic and advanced engineering education.

# Part C. Basic Engineering Education

## 1. INTRODUCTION

*Basic engineering education, as just defined, comprises post high-school education up to a level determined by a general consensus as the ideal minimum of formal education required preparatory to entering a career in engineering.* It is remarkable that for over a century the bachelor's degree has remained the accepted minimum for entering the engineering profession, considering the rising academic requirements in other professions.

Basic engineering education is to be distinguished from technician training. The latter is a related path of education having a different emphasis and leading to different goals. It is also to be distinguished from advanced education in that the latter extends formal engineering education beyond the minimum consensus level.

### Responsibilities of Basic Engineering Education

In view of the nature of engineering and of the problems facing engineers in the days ahead, considered in Part B, the following appear to be the responsibilities of basic engineering education at this time.

(1) *To the Individual.* The primary responsibility is to enable the individual to develop such natural talents as he may have and to provide him the knowledge, skills, understanding, and appreciation that will encourage him to pursue a personally rewarding career of work and study in engineering during his working years.

(2) *To Society.* There is the responsibility to guide the total education of a group of able young people during an impressionable and formative period so that, as professional persons, publicly or privately employed, they will conscientiously, wisely, and competently supply valuable engineering services to society.

(3) *To the Engineering Profession.* There is the responsibility to supply the engineering profession with a group of embryonic engineers able at graduation to perform satisfactorily the simpler tasks of an engineering organization under guidance, capable and eager to develop into engineers able to handle assignments of progressively greater difficulty and responsibility, under diminishing supervision.

### General Objectives

The general objectives of engineering education as found in the Report of the Committee on the Aims and Scope of Engineering Curricula are judged to be as valid today as when they were published. They have been placed in Appendix II. They are particularly applicable to basic engineering education as just defined. It seems appropriate to supplement them with the following list of goals which appear to be in need of emphasis at this time. (1) To prepare the student, ideologically, for constructive participation in the competitive, profit motivated economy. (2) To prepare the student for a world of accelerating technological change—one in which he must continually learn and learn rapidly the new facts, new methods and even new principles of science that will almost certainly be discovered or evolved. Intellects disciplined to be agile, flexible, alert, and active are needed as never before. (3) To help the student to become cognizant of the changing needs of mankind while interpreting and implementing the ever increasing body of knowledge; as a builder of bridges between the world of science and the world of man to become sensitive, farsighted, responsible, and dynamic in joining these two worlds for the progress of human fulfillment (Ref. C-1). (4) To develop in the student the conviction that education is a self-discipline, and to place a greater responsibility for learning on the individual. (5) To impress upon the student that education must be a continuing process throughout his professional career. (6) To encourage the student to recognize the wide applicability of engineering methods and to become skillful in their use.*

*The Curriculum*

To discharge the responsibilities and accomplish the objectives above outlined, the basic curriculum must be constantly revised to incorporate new subject matter but must retain a core of tested material from the past. It should not be too rigidly specified.

The Goals Committee endorses the emphasis on mathematics, physical science, engineering science, and engineering analysis, design and engineering systems expressed in the "Grinter Report" (Ref. C-2). Astonishing developments in these fields are continually taking place.

This report recognizes the importance of computers which enable the engineer and the engineering student to utilize mathematics and physical and engineering science in analysis and design—especially of engineering systems—to an extent undreamed of only a decade ago. They also find application in many other fields bordering on engineering.

The report recognizes the engineer's increasing share of responsibility for solving many problems of modern society and accordingly the Committee recommends a renewed attention to the humanities, to the new insights that are coming from the social sciences and to the whole area of communications.

A new study of this area of engineering education is proposed.

Detailed considerations of the subject matter of the curriculum including suggestions for attention to engineering ethics appear in Appendix III.

*The mode of thought which underlies science and technology has been characterized by the following:
1. Longing to know and understand
2. Questioning of all things
3. Search for data and their meaning
4. Demand for verification
5. Respect for logic
6. Consideration of premises
7. Consideration of consequences.
Reference: "Education and the Spirit of Science" Educational Policies Commission, 1966, page 1 and 15.

# 2. PLANNING AND ADMINISTERING BASIC ENGINEERING EDUCATION

*Various Functions of Basic Engineering Education*

It seems clear that some will view the five-year master's level program (or the first four years of such a program) as a general or basic education, others as education mainly for immediate productivity and still others as preparation for specialized, advanced study either in engineering or in another field.

(1) *As General Education.* Many programs in engineering education are broad—they span the basic sciences, the engineering sciences, the social sciences, and the humanities and communications and offer experiences in problem-solving. At the same time they include the study in some depth of an engineering discipline.

Actually, only a small proportion of the undergraduate engineering curriculum today is concentrated on highly specialized subjects which reflect the current nature of the art. Indeed, many view the specialized courses in undergraduate engineering as constituting no more than a major in a typical liberal arts school. (The engineering curriculum has an advantage over the liberal arts curriculum of providing an integrative experience through design or laboratory courses.)

Engineering education gives students a foundation for engaging successfully in a variety of the more important activities of this age. They are admitted to graduate schools of business or of industrial management in increasing numbers, and to professional schools of law, of medicine, and even of theology.

It is believed that much of the strong support for established four-year baccalaureate programs in engineering is based on the judgment that these curricula prepare a person to fill positions in industry that require

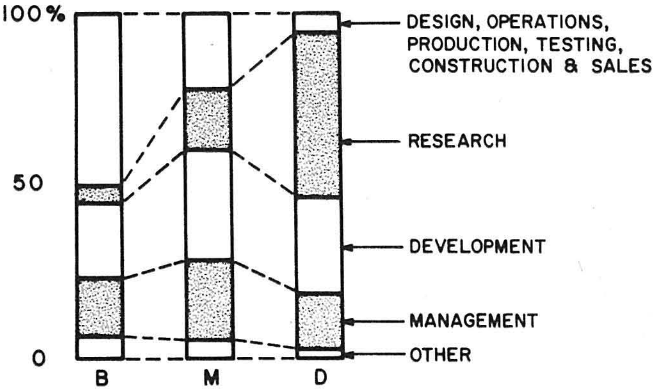



Figure C-1. Functional responsibilities by degree level.

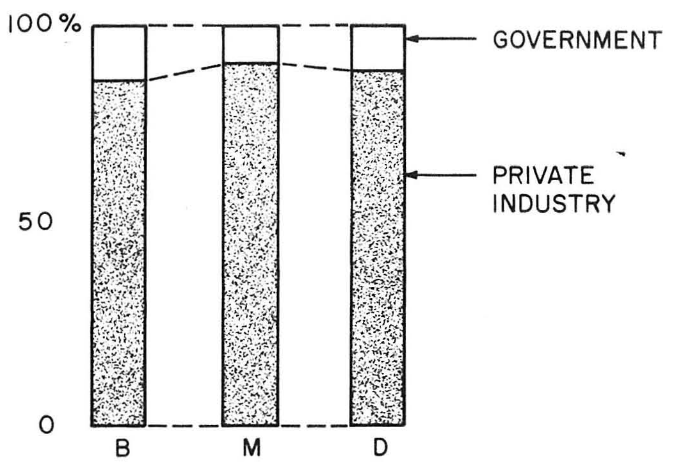



Figure C-2a. Type of employer by degree level.

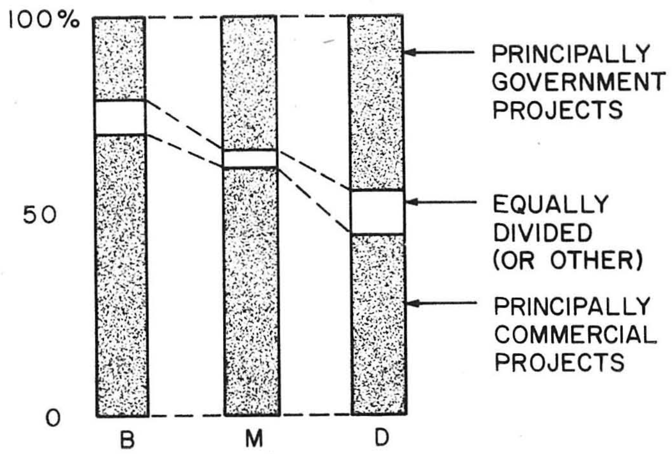



Figure C-2b. Type of project for those employed in private industry by degree level.

decision-oriented people—to choose a course of action and take the necessary steps to solve a problem. Thus the ideal basic engineering curriculum may be viewed as education for action in today's world.

(2) *For Immediate Productivity.* The results of the Industry-Government Survey indicate that engineers are used for a wide spectrum of activities ranging from the highly scientific to the sub-professional.

The Survey shows that degree holders at *all* levels are to be found in *all* of the engineering functions, although the proportion of the degree holders in each function is different. Figure C-1 shows both similarities and differences of function in terms of degree levels.

The Survey also revealed that the division of engineers between government and private employers was about the same for the different degree levels (Fig. C-2a, C-2b) although the proportion of engineers working in private industry on government projects increases progressively from the bachelor's to master's to doctoral levels.

That industry wants four-year baccalaureate graduates who are educated for immediate productivity is clearly shown in Table 4, Information Document No. 8 of the Goals Study (Ref. C-3). Perhaps the best indication of this insistent and continuing demand is that about 40 percent of the management respondents from the national sample of organizations indicated a preference for a specialized as compared to a common undergraduate curriculum. Graduates from such programs, they believe, rapidly adapt to the technical requirements of their position and require little on-the-job training. Similarly, about one-half of the practicing engineers agreed with the view that a bachelor's degree program was sufficient preparation for their work, and a little over 40 percent of the middle management representatives held the same view of the educational needs of engineers employed in their organizations.

It is the contention of this report that the basic engineering program—of five years duration—enables engineers to be better prepared for immediate productivity than does the four-year program but the plan proposed does not cut off the supply of four-year men. It allows for their separation from the program at the end of four years—with a bachelor's degree—if that is their choice. That fewer will do so as time goes on seems inevitable in the light of discernible trends.

(3) *As Preparation for Advanced Study.* It is obvious that one purpose of basic education is preparation for advanced study, but it should be understood that there are several varieties of programs that prepare for advanced graduate work as shown in Figure D-18. The five-year basic engineering programs discussed in this report would seem to be especially helpful as preparation for advanced study in design, research, development, and teaching—furnishing, as they would, the fundamental tools of understanding for such study.

#### *Diversity of Educational Programs*

It has been shown in the previous sections of this report and from other reports of the Goals project (Ref. C-3, C-4, C-5) that there is great diversity: (1) in the actual educational preparation of practicing engineers; (2) in the needs for engineers of varying types expressed by the many organizations that employ engineers; (3) in the talents and interests of students; (4) in the existing curricula and institutions that administer them; and (5) in the opinions concerning curricula expressed by engineers and engineering educators. Many changes have taken place in industry which have created needs for new types of engineers. The growth of research and development activities since 1945 in a large number of expanding industries has also had its impact upon engineering education. Educators and engineers must anticipate these changes; they cannot afford the luxury of waiting for things to "settle down" to see what course the future will take.

In October 1965 there were 54 distinct categories of curricula or options that were accredited by the ECPD—899 in all (Ref. C-6).

Since it is impossible to predict precisely what the engineering tasks of the future will be, the curricula should include those fundamental studies that furnish widely applicable understanding. This is the philosophy behind the selection of suggested subjects for basic education curricula.

#### *The Five-Year Basic Program*

It would seem that the engineering profession would be best served if a variety of master's level basic engineering programs were offered, programs in traditional fields of engineering (C.E., M.E., etc.) and in new fields and in combinations of these fields; also programs organized along functional lines: research, design, management, etc. Such programs should achieve a level of instruction higher than the present bachelor's degree, and not merely add a fifth year of undergraduate courses. At the same time, they should be designed for a substantial number of students. It is the contention of Part D of this report (see Section 1, subheading "Maintenance of Quality") that quality of students in graduate programs has been and may continue to be maintained as the numbers increase.

Of the 177 U.S. educational institutions which had in October 1965 one or more accredited programs in engineering, 13 had accredited fulltime day programs of both 4 and 5 years' duration leading to a bachelor's degree and 13 institutions had accredited 5-year programs leading to a master's degree. One institution belonged to both categories. Consequently there were 25 institutions which had accredited 5-or-more-year day time regular programs leading to a first degree in some field of engineering. (First degrees in a particular field are the only ones that are examined for accreditation—according to the present policy of ECPD.) (Ref. C-6).

Since the date of compilation of this data, at least one of the institutions which then reported 5-year bachelor's programs had decided to go to 5-year master's programs. In the spring 1966 issue of Cornell's Engineering Quarterly appears the following: ". . . the first Cornell degree with an *engineering* designation is the Master of Engineering degree, awarded after a five-year integrated study program in traditional fields. . . ." (Ref. C-7).

In the Engineering Master Plan Study of the University of California which is an overall plan for teaching of engineering on all the campuses of the University appears the following: . . . "It is proposed that the master's degree should succeed the bachelor's degree as the University's first professional engineering degree. It is believed that most of the University's engineering BS recipients will be interested in, and will be qualified to proceed directly into, a master's degree program. . . . In development of the idea of the 5-year first professional degree, the added year was deliberately made a graduate year. . . . It was . . . concluded to be feasible to develop an undergraduate-plus-graduate program on an integrated 5-year basis, with a bachelor degree given at the four-fifths point of the program" (Ref. C-8).

It is expected that career-centered five-year programs will be offered at an increasing number of institutions as a preferred route leading to a professional career in engineering practice as has been done in some present four and five year baccalaureate programs.*

The social-humanistic stem of these programs would be designed to serve the professional needs of the engineer. The liberalizing values of the strictly scientific and technological courses would be fully exploited in accordance with the view that it is possible to become liberally educated by the study of professional or specialized subjects in a liberal manner.

All the courses of the curriculum would be fused into a coherent professional complex. It is thought that at most institutions these programs would lead to a master's degree at the end of five years. While designed for those who plan to go into practice—especially into design and planning rather than into operation or sales—they would also be appropriate as basic education for careers in teaching and research. They would not exclude graduates from the bachelor's programs (nor from any others) should these students have the requisite preparation for entering the program at some level, but they would not be planned for the special convenience of the four-year bachelor's group. These programs would not be intended to replace but rather to supplement the usual master's programs in the various fields and functions of engineering. It is expected, however, that because of their advantages, they would in the course of time, come to replace the programs now offered as preparation for the practice of engineering. They need not and must not be inferior in quality or in level of advancement to the accepted master's level standards. (See Part D, Section 1, subheading "Maintenance of Quality".)

### *The Administration of Educational Programs*

(1) *Existing programs should be made flexible.* Many of the present programs are too rigid to meet the engineering needs of tomorrow. Tightly specified curricula tend to delay modernization and discourage valuable experimentation. Provision of free electives with an effective advisory system would permit students to follow programs which offer the greatest challenge to their abilities and the best preparation for their next steps after graduation.

Flexibility of individual programs is needed to allow for the diversity of interests and talents of particular students and provide engineers with a wide range of competencies to meet the needs of industry and government.

The principle of flexibility will permit engineering schools to offer their strongest programs, building upon established strengths, free from constraint to offer programs they are not prepared to administer.

(2) *Expanded opportunities for interdisciplinary study are needed.* Many of the recommendations for curricular changes suggested by engineering graduates point to the existence of a clear demand for and interest in interdisciplinary programs. Some students may have the ability and desire to begin interdisciplinary work during their baccalaureate programs but some programs are so specialized that the student has no opportunity to study any engineering subject in depth outside of his own field.

(3) *Credit hour requirements should be reduced.* One of the aims of educators has been to find the balance of courses needed to make engineering education a general scientific-technological education. The movement toward general education has often meant addition of new courses to the curriculum to the point that it has become difficult to obtain a bachelor's degree in eight semesters. Compared to requirements for a bachelor's degree in mathematics, physics, and chemistry, engineering demands almost an additional semester's work (Table C-1).

The restrictive effect of an excessive academic load

* Requirements for licensing in engineering are controlled by 53 separate boards but recommendations have been made recently by the National Council of State Boards of Engineering Examiners that one year beyond the bachelor's degree be a requirement for future licensing. (Proceedings of the 44th Annual Meeting of NCSBEE, pp. 138-142, 1965)

TABLE C-1

HOURLY REQUIREMENTS FOR BACCALAUREATE IN ENGINEERING AND SCIENCE AT 52 RANDOMLY SELECTED INSTITUTIONS

| TYPE OF SCHOOL | CHEM. ENG. | CIVIL ENG. | ELEC. ENG. | MECH. ENG. | ENGR. AVG. | CHEM. | MATH. | PHYSICS | SCIENCE AVG. |
|---|---|---|---|---|---|---|---|---|---|
| | mean range | mean range | mean range | mean range | mean range | mean range | mean range | mean range | mean range |
| PUBLIC | 144.4 131-157 | 143.4 127-156 | 142.7 131-152 | 142.6 131-152 | 143.1 130-153 | 131.2 106-151 | 129.6 115-151 | 129.6 118-151 | 130.2 113-151 |
| PRIVATE | 140.5 120-152 | 142.9 129-156 | 130.7 120-152 | 140.1 123-152 | 140.8 120-152 | 128.9 117-143 | 125.7 117-145 | 125.7 117-144 | 126.8 117-142 |
| PUBLIC and PRIVATE | 142.9 120-157 | 143.1 127-156 | 137.2 120-152 | 141.5 123-152 | 142.0 120-152 | 130.0 106-151 | 127.8 115-151 | 127.8 117-151 | 128.6 113-151 |

often prevents the student from engaging in other worthwhile activities of college and community life, and in courses outside of his major field where he might gain the breadth of perspective and develop the creative imagination needed by the engineer of the future. There appears to be a lack of evidence that credit hour requirements for graduation are correlated with the quality of the products.

(4) *Many prerequisite courses should not be required.* The requirement of many prerequisite courses often unnecessarily discourages qualified students in one area from taking courses in other fields. Wherever possible, prerequisite material which is not extensive in scope or of a highly advanced nature should be acquired through self-directed study.

(5) *Provisions for transfer into engineering are needed.* Too many engineering colleges make it almost impossible for students to transfer to engineering above the freshman level. There is real opportunity to increase the enrollment of first-rate students other than through the freshman class.

(6) *The role of cooperative education should be recognized.* It is generally recognized that actual practice of engineering periodically interwoven with classroom and laboratory instruction can provide motivation and reinforcement of the education of certain students and can result in a balance of their intellectual development. Currently 50 colleges of engineering in the United States provide curricula on the cooperative plan largely at the baccalaureate level. These curricula have much to offer to engineering education of the future both undergraduate and graduate, basic and advanced. They are applicable to instruction in engineering systems design, to research and development, to construction, production, operation, management, and sales.

With increased emphasis on continuing education throughout a professional career, early development of a capacity to deal with alternate periods of study and practice has many advantages.

And the cooperative plan extends educational opportunities to talented students of limited financial resources.

### *Diversity of Educational Institutions*

The great task of providing the engineering manpower needed in the days ahead requires the full and efficient utilization of the many diverse educational institutions of the land—each performing its appropriate and distinctive educational function.

A high governmental official has written, "Each of the different kinds of institutions has a significant part to play in creating the total pattern, and each should be allowed to play its role with honor and recognition.

"We do not want all institutions to be alike. We want institutions to develop their individualities and to keep those individualities. None must be ashamed of its distinctive features so long as it is doing something that contributes importantly to the total pattern, and so long as it is striving for excellence in performance. The highly selective, small liberal arts college should not be afraid to remain small. The large urban institution should not be ashamed that it is large. Each institition should pride itself on the role that it has chosen to play and on the special contribution which it brings to the total pattern of American higher education" (Ref. C-9).

Functions of various kinds of institutions offering engineering and technician programs are discussed in Appendix IV.

*Diversity and not uniformity of educational institutions as well as the programs they administer is the recommendation of the Goals Committee.*

### *Emerging Patterns of Engineering Education*

To summarize what has been said elsewhere in this report, there appear to be several patterns of engineering education—existing or in prospect—which are favored or held to be satisfactory engineering programs by significant numbers of engineers and teachers: (1) Four-year programs in engineering leading to a bachelor's degree followed by graduate programs leading to a master's degree. (2) Five-year programs in engineering leading to a bachelor's degree that may or may not be followed by graduate work. (3) Five-or-more-year programs in engineering leading to a master's degree in engineering or in a specialized branch of engineering. A bachelor's degree may or may not be awarded at the end of the first four years of this program. This program as well as the previous one is intended primarily for those who intend to practice engineering at a professional level. (4) Four-year programs leading to a bachelor's degree not necessarily in engineering to be followed by an engineering program, probably of two or more years duration, leading to a master's degree or a higher degree in engineering. Persons have entered the profession of engineering by way of the liberal arts route. Future popularity of this practice is uncertain, but it should be encouraged. (5) Four-year programs leading to a bachelor's degree in engineering not necessarily followed by graduate work. There are many engineers who feel that this program is still satisfactory for many who properly call themselves engineers.

The Goals Committee urges each institution to offer those programs (and only those) which will optimize its individual contribution to engineering education.

# 3. ACCREDITATION

At the present time accreditation is of two kinds: *institutional (or general)*, in which the total capability of the college or university is involved, and *curricular (or special)*, in which the capability in a particular field of study, e.g., medicine, engineering, etc., is the focus. Institutional accrediting is now conducted under the auspices of the several Regional Associations, and curricular accrediting in the engineering fields is conducted by Engineers' Council for Professional Development.

It should be emphasized that ECPD presently accredits curricula only in institutions which have first received institutional accreditation by a Regional Association. This is a desirable practice and the Goals Committee recommends that it be continued.

In recent years accrediting by Regional Associations has been by level (junior college, bachelor's degree, master's degree, doctor's degree). In contrast, the focus of ECPD accreditation is on what it has defined as "first professional degree" rather than on "undergraduate" or "graduate" degrees.

Accreditation identifies, for parents and prospective students, schools which meet acceptable standards of engineering education; and, on the other hand, it gives assurance to the public and the profession that the graduate's education has been obtained in an institution meeting these standards. The process of evaluation for accreditation gives the institution an opportunity to have its offerings judged in a court of professional opinion.

These evaluations frequently identify deficiencies and point to remedies, thereby giving guidance for planning to all administrative levels of the institution. Accreditation stimulates the college and its departments to perform self-studies, and encourages the faculty to evaluate and compare its courses and professional activities with those in other schools and in industry.

In the course of the Goals Study, the importance of accreditation has been repeatedly emphasized as a potent influence on engineering education and consequently upon the engineering profession. Therefore, the Goals Committee recommends that every effort be made to develop accrediting policies and procedures which will enhance rather than inhibit innovation and experimentation. In particular, flexible procedures are favored which will take into account the emerging role of master's degree programs in basic education and will encourage new disciplines and interdisciplinary programs that may overlap or integrate several fields. *Sufficient flexibility should be provided to allow accreditation of either the bachelor's degree or the master's degree programs or both and accreditation of either curricula (as C.E., Ch.E., etc., or unified engineering) or overall accreditation of an engineering unit (college, school or department). Accreditation should be awarded on the basis of attainment of the particular stated goals of individual institutions.*

### Arguments for Permitting Unit-Wide Accreditation

(1) Unit-wide accreditation would provide a mechanism for the evaluation of programs in emerging new fields or in new combinations of fields as well as of the traditional specialized programs (E.E., M.E., etc.). (2) The present procedure of curricular accreditation in some cases inhibits innovation and experimentation in the organization of engineering programs, e.g., those centered around function rather than field, interdisciplinary programs, unified programs, honors programs, etc. (3) Although it may be argued that accreditation of the overall unit could result in failure to expose weaknesses in particular curricula (as M.E., C.E., etc.) it may also be argued that the unit accreditation would give a more comprehensive evaluation of the total educational program of the engineering student. (4) The accreditation of the institution on the basis of its own adopted educational goals places the responsibility for the quality of all offerings upon the institution itself where, in fact, it now resides. (5) The examination by ECPD inspection teams of course coverage of the curricula, to say nothing of the details of subject matter and pedagogical procedures, are necessarily cursory. It is thought that, in actual fact, the judgment of the inspection teams is based now in large part upon their evaluation of the engineering unit as a whole rather than upon curricular details. Thus, over-all engineering unit accreditation would more nearly correspond to the reality of present procedures.

# 4. TEACHERS AND TEACHING METHODS

### Academic Level of Faculty

The younger faculty member should be cognizant of the growing importance of the doctor's degree as a requirement for engineering teaching. The evidence is clear from the 1959 and 1963 surveys of engineering faculty by the Ford Foundation (Ref. C-11) that the academic preparation of engineering teachers, as measured by academic degrees, has increased in recent years, and that now a significant percentage of the faculty have attained the doctor's degree (Table C-2). There has been a notable increase in the proportion of core faculty members holding doctor's degrees in all fields and at all age levels (See also Figure D-21).

A study of the 1963-64 recipients of the doctor's degree showed that 36 percent of those in engineering went into teaching compared to 29 percent of those in physics and 23 percent of those in chemistry—the first time that a higher percentage of engineering than of science doctoral graduates went into teaching (Ref. C-12).

These developments are viewed as a growth in the strength of engineering education which should be encouraged in the future. But academic credentials are not a perfect measure of development and advancement. Significant anomalies do in fact occur.

TABLE C-2

PERCENTAGE OF CORE FACULTY AT ENGINEERING SCHOOLS WHOSE HIGHEST DEGREES ARE THOSE INDICATED*

| Degrees | 1963 | 1959 |
|---|---|---|
| Doctorate | 45% | 33% |
| Masters or Equivalent | 44 | 48 |
| Bachelor's | 8 | 16 |
| No Degrees | 1 | 3 |

PERCENTAGES OF FACULTY IN VARIOUS ENGINEERING DEPARTMENTS WHO HOLD DOCTOR'S DEGREES

| Department | 1963 | 1959 |
|---|---|---|
| Ch. E. | 85% | 74% |
| Met. E. | 75 | 62 |
| Aero. E. | 56 | 51 |
| E. E. | 49 | 35 |
| C. E. | 37 | 25 |
| Mech. E. | 34 | 22 |
| Ind. E. | 31 | 20 |

PERCENTAGE OF VARIOUS AGE GROUPS OF ENGINEERING FACULTY HOLDING OR SEEKING DOCTOR'S DEGREES

1963 Doctorate

| Age | Holders | Seekers | Total |
|---|---|---|---|
| 27 & under | 33% | 20% | 53% |
| 28-32 | 56 | 21 | 77 |
| 33-37 | 55 | 19 | 74 |
| 38-45 | 50 | 11 | 61 |
| 46-55 | 39 | 4 | 43 |
| 55 & over | 27 | 1 | 28 |

1959 Doctorate

| Age | Holders | Seekers | Total |
|---|---|---|---|
| 27 & under | 22% | 21% | 43% |
| 28-32 | 38 | 19 | 57 |
| 33-37 | 40 | 17 | 57 |
| 38-45 | 39 | 8 | 47 |
| 46-55 | 32 | 3 | 35 |
| 55 & over | 18 | 1 | 19 |

* The core faculty is defined as all full-time instructors and professors who teach engineering or engineering science subjects in engineering faculties, or who supervise engineering theses, except those instructors who are under 33 years of age and who are seeking advanced degrees at the institutions where they are employed.

### *Supervision of Teaching of Young Instructors*

In 1960 an important report on the subject of faculty development and related matters was issued by a committee of the ASEE which stated that "the most effective faculty development practice is the conscientious supervision of early teaching efforts. . . ." Both deans and young teachers agree on this point; but they ". . . tend to *disagree* on the extent to which this supervision is in fact provided." The report also stated that ". . . discussion or seminar groups . . . can contribute to the growth and development of a young faculty member" (Ref. C-13).

### *Educational Programs for Faculty*

The Ford Foundation has established and is administering a program to help young engineering faculty members get a taste of the environment an engineer must enter when he leaves school and goes into competitive enterprise. It is hoped that this can be accomplished by providing young faculty members with experience of professional practice at the highest levels of decision making (Ref. C-14).

The need for such a program arises from the fact that young men are entering faculty careers with doctoral degrees but with little, if any, experience in the practice of engineering. Particularly is this true of their contacts with non-military product design and development in which economy, market appeal, ease and safety of operation, customer and employee relations are often important determining factors. If engineering schools are to keep appropriate contact with the practicing profession, these young men of high sophistication in the sciences and mathematics must somehow be made aware of engineering in which decisions are influenced by many factors other than the strictly scientific.

In 1964 the Atomic Energy Commission and the National Science Foundation jointly supported 6- to 8-week institutes in reactor and radioisotope technology, and allied subjects for college teachers. In the period 1956 to 1965 a number of similar institutes were conducted for the AEC by the ASEE (Ref. C-15).

A series of four unique summer institutes devoted exclusively to discussion of the "teaching-learning" process were held at Pennsylvania State University, 1960-63, under the sponsorship of the Educational Methods Division, ASEE, and the Ford Foundation. A number of campus and regional follow-up workshops have been held and others are being planned (Ref. C-16).

A study conducted by E. K. Kraybill of the effectiveness of teaching of those who participated in the institute—before and after their participation—indicated that ". . . Attendees, who were subject to the Institute Program, did develop classroom behavior after the Institute which, as perceived by their students, can be considered as increased teaching effectiveness" (Ref. C-17).

The National Science Foundation has supported many college teacher programs at educational institutions throughout the nation. A pamphlet published by the National Science Foundation in 1965 contains some 40 closely packed pages listing various college teacher programs including many especially suitable for teachers at engineering schools—all supported by this agency.

Since 1963, summer institutes have been held under the joint sponsorship of the ASEE and the National Aeronautics and Space Administration (NASA) to provide an opportunity for engineering professors to engage during a 10-week summer period in research activities at one of the NASA research centers while at the same time participating in advanced educational activities (Ref. C-18). Since 1964, similar programs have been sponsored by the Office of Civil Defense (OCD).

### *Concern for Maintenance of Professional Competence of Faculty*

As they continue to grapple with the multiple problems of research, instruction and public service, many faculty members have become concerned about maintaining their professional competence. Figure C-3 summarizes the almost universal concern expressed by the Institutional Study Committees over faculty obsolescence. Principal suggestions made by the committees for as-

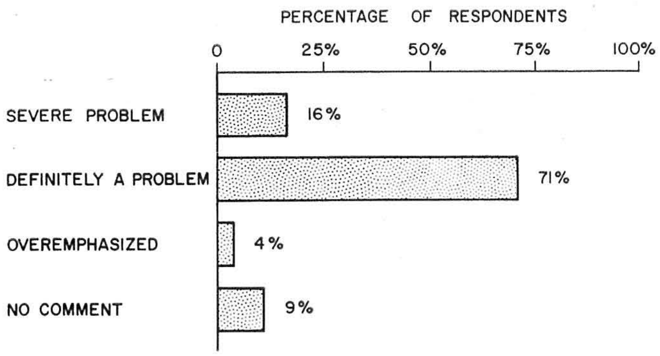



Figure C-3. Opinions of Institutional Study Committees about faculty obsolescence.

sisting faculty in keeping up to date were: (1) sabbatical leaves (87 percent), (2) research (72 percent), (3) industrial experience (64 percent), (4) consulting (60 percent), (5) reduction of teaching loads (56 percent) (Ref. C-5).

The 1963 survey of engineering faculty members by the Ford Foundation revealed that two-thirds of the regular faculty surveyed had not participated in any summer institutes or conferences for the purpose of improving or maintaining their competence as faculty members. However, almost all of the engineering faculty members surveyed by the Ford Foundation (Ref. C-10) reported some type of professional growth activity (research, consulting, industrial experience, self-study).

### *Contact Between Faculty and Practicing Engineers*

Eighty-two percent of the Institutional Study Committees indicated that closer ties between the educator and the practicing engineer are desirable (Ref. C-19). Fifty-six percent of the responses received to Recommendation 8 of the Preliminary Report called for close cooperation between colleges on the one hand and industry and government on the other, to encourage practicing engineers to participate directly in academic instruction and to arrange for teachers to gain practical experience in industry and government on a semester-long basis (Ref. C-20). Only one percent disagreed and 41 percent did not comment.

In response to a question regarding the proportion of engineering faculty which ought to have industrial experience, 21 percent of the study committees responding felt that all faculty members should have some industrial experience, 74 percent felt that at least three-fourths of the faculty should have industrial experience, and 87 percent felt that at least one-half should have industrial experience (Ref. C-21).

Engineering education, the engineering profession, industry and government should jointly develop a variety of programs designed to enhance the development of engineering faculty members as practicing engineers through the effective use of leaves of absence, summer employment, consulting and research opportunities.

It follows inevitably from these expressions that professional registration by the majority of engineering faculty members is desirable and should be strongly encouraged.

### *Contact Betweeen Faculty and Students*

Professional and educational study committee reports frequently stressed the need for greater contact between engineering faculty members and students, especially at the freshman and sophomore level (Ref. C-22)—two-thirds emphasizing the importance of student-faculty contact.

The pressure and opportunity for increased professional activities on the one hand and the need for increased student-faculty contact on the other presents engineering education with a dilemma. The increasing professional activities of engineering faculty members in research, consulting and industrial experience should be encouraged because the effects of these activities are in general regarded as helpful to undergraduate and graduate instruction, but if or when they are found to be distracting, diverting too much time and energy of the faculty member away from his teaching, then these extra-curricular activities should be diminished.

### *Educational Innovation and Experimentation*

Powerful new devices and systems, developed during the last few decades, have had an impact not only on higher education, but also on elementary, secondary, and adult education. Some notable examples are closed circuit television, programmed learning, language and listening laboratories, self-instructional laboratories, audio-visual aids including films, slides, transparencies and video tapes, as well as systems of information storage and retrieval. Systematic applied research studies of educational methods, including experimental design, are based on a rapidly growing reservoir of fundamental information about human learning. Advantage has been taken in these studies of new methods of analysis and synthesis made possible by computers.

Engineers and engineering educators have been directly and indirectly involved in the design and development of these systems as well as pertinent devices and hardware. Yet few innovations in engineering education itself have been widely adopted. Many ancient practices continue unquestioned such as the 50-minute, three-day-a-week lecture, the chalk-board as the main visual aid, the one-teacher course or section, the two- or three-hour laboratory, ten-year-old cook book experiments, the 18-20 hour load, the 16-week semester, the rigidly proportioned curriculum (25 percent engineering science, 20 percent social-humanistic studies, etc.), the policy of designing curricula exclusively along traditional lines, etc. The Goals Study has sensed an unrest not only among the younger members of the faculty in engineering, but also among the indomitable innovators who have over the years met with strong resistance whenever and wherever significant changes have been proposed.

Yet, in spite of the resistance, some important and significant changes have been and will continue to be made. It is suggested that engineering educators encourage experimentation and innovation by using not only the many new educational devices and systems, but also by employing improved methods of educational research —including experimental design.

# Part D. Advanced Engineering Education

The sections to follow are devoted to a study of engineering education at the "graduate" level and of engineers who sought and attained graduate degrees. This use of the term "graduate" is accurate in the *academic* context (as explained at the end of Part B), yet in the *professional* context the distinguishing feature of the study is that it is concerned with *advanced* engineering education, undertaken optionally by those engineers who had already completed the *basic* education for which the engineering profession has established a consensus as to *content* and *level.* Basic engineering education is discussed in the preceding part of this report.

There is a real need for the reader to have a clear understanding as to these two different frames of reference: academic and professional. It is as though one describes the same physical domain in two alternative sets of coordinates (see Fig. B-6). There is only one domain, but in choosing the appropriate set of coordinates one can clarify or simplify the description of particular phenomena.

As a profession matures and progresses, an academic degree which was previously regarded as "advanced" comes to be accepted as "basic." This phenomenon occurred in the 19th century with the bachelor's degree in the engineering profession; the consensus became clear that formal education to at least the bachelor's level should be the proper minimum for commencing a career in engineering. Now, however, a few schools have already adopted the master's degree as the basic engineering degree, and in at least one field (sanitary engineering) there seems to be a consensus already that the master's degree is the basic degree. Because of many considerations that are explained elsewhere in this report, especially in Part B, the Goals Committee *recommends* that the master's degree should be more generally accepted as the basic degree in engineering.

There are many advantages in maintaining the concept of a professional frame of reference superimposed upon the conventional academic degree structure. It permits considerable flexibility for individual arrangements—the basic engineering degree can be at different levels at different schools, and at different levels for different fields. Finally, it should be noted that the other professions also have developed professional degree patterns. In law, for example, the basic degree (first professional degree) is the LL.B. or J.D. obtained usually after three years of study beyond the A.B. degree. Similarly, in business administration and in medicine there is a professional consensus as to the basic education, and this has changed over the years with respect to the academic structure.

Advanced education in the engineering profession differs in two important respects from basic education. First, the students undertake advanced study on a voluntary or *optional* basis, since there is no professional consensus that such additional study is expected of them. In the recent past all students who went beyond the bachelor's degree have been in this category. We thus have an interesting measure of educational motivation among engineering students and of professional needs as perceived by students. Secondly, advanced degree programs are little influenced by any professional consensus as to *content.* This provides, on the one hand, freedom for universities to experiment and for students' programs to be quite flexible. It makes more difficult, however, the question of professional accreditation (see Sect. 12).

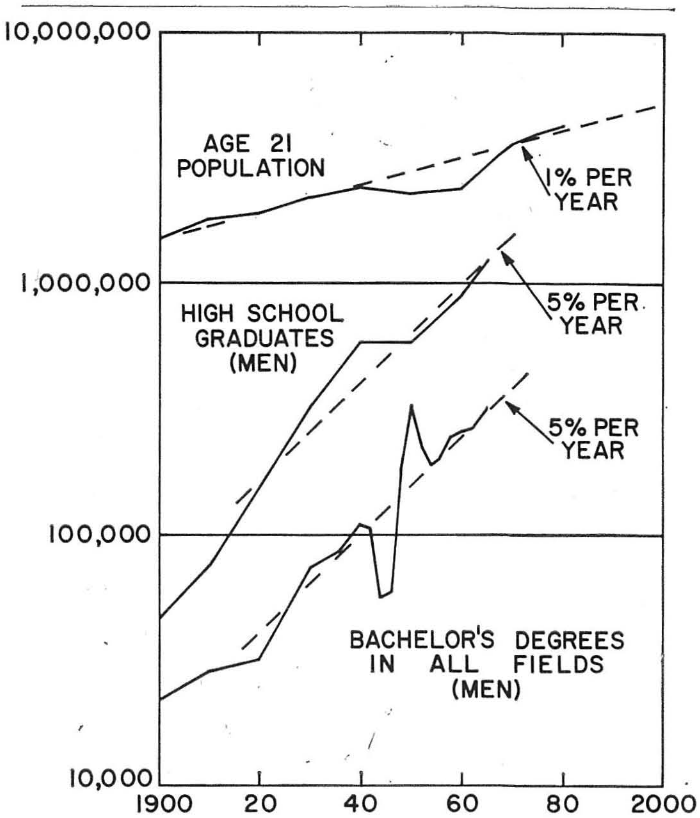



Figure D-1. Growth of U.S. college-age population, annual number of high school graduates, and annual number of bachelor's degrees in all fields.

# 1. NATIONAL TRENDS AFFECTING ENGINEERING EDUCATION

Advanced engineering education, which in the past has been synonomous with graduate education, played a relatively minor part in engineering education 30 years ago, but now has a crucial and central role in the development of engineers. Formerly of interest to only a few individuals, graduate education today is undertaken by more than 40% of those who receive bachelor's degrees in engineering. This percentage is growing steadily and will soon be over 50%.

### *Growth of U. S. Education*

In order to understand the growing role of graduate education generally in the United States, it is important to recognize the historical and social trends that are occurring. It must first be noted that our nation's population is growing. This is illustrated by the uppermost curve in Fig. D-1, which shows that the college-age population is growing at an average rate of about 1% per year. The next two curves portray the annual numbers of male high school graduates and bachelor's degree graduates. It is clear from these curves that *an increasing fraction of our population is seeking education at both the high school and college levels.* In 1966, approximately one-half of the U. S. adult population (age 25 or over) had completed four years of high school or more, whereas in 1947 only about one-third had done so. In 1966, about 10% of the adult population were college graduates, compared to only 5% in 1947 (Ref. D-1).

Furthermore, this growth in education is not a recent phenomenon, but can be traced back through the entire course of this century. There have been, of course, perturbations caused by the depression of the 1930's and by World War II; nevertheless, the long-term trend remains in evidence. Since engineering is an important segment of this national growth, it would appear that engineering education must grow as a result of social forces that are much broader than engineering itself. In other words, *engineering education can be expected to advance as part of the national desire for higher levels of education,* in addition to any specific industrial or technological needs of the country.

A graphic picture of the growing scope of college-level education in the U.S., as measured by degrees awarded each year, is presented in Fig. D-2. The first graph in this figure is for all fields of study and the second is for engineering alone. The similarities in shape between the curves for engineering and those for all fields are noteworthy; in fact, the similarities are more striking than the differences. In each case a steady growth is evident, although with some fluctuations. There are noticeably reduced levels during World War II, compensated by sharp increases immediately thereafter. *The growth in graduate degrees since World War II is not unique to engineering, and hence should not be attributed merely to dramatic changes in technology.* Instead, we seem to be following long-term growth trends that are in keeping with the national increase in higher education (Refs. D-2, D-3).

It is interesting to note that *doctoral work in engineering is not a recent innovation but is, in this country, as old as doctoral education generally.* The first earned doctor's degree in the U.S. in any field was awarded in

1861 at Yale, and only two years later the first doctor's degree in engineering (and the fifth doctor's degree in any field) was awarded at the same institution. This first engineering doctorate was awarded to Josiah Willard Gibbs, whose thesis title was, "On the Form of the Teeth of Wheels in Spur Gearing." Later, Gibbs achieved world-wide fame for his work as a mathematical physicist (Refs. D-4, D-5). Somewhat surprisingly, the first doctor's degree in engineering preceded the first master's degree, which apparently was awarded in 1879 at Iowa State College (Ref. D-6).

The curves in Fig. D-2 show that graduate education in engineering has been growing at a faster rate than undergraduate education, and hence is becoming a more important component within engineering itself. With respect to growth in numbers it is interesting to note that in the period around 1900 the ratio of total graduate degrees to bachelor's degrees in engineering was only 1:100; by 1930 the ratio had progressed to about 1:20, in 1960 it was 1:4; and in 1966 it was 1:2. The long-range trends indicate that the ratio will reach 1:1.5 within a decade.

This growth in graduate education has accompanied a rising level of technology in the national life and rising aspirations on the part of individual students. The latter phenomenon was brought out in the Institutional Reports, which portrayed a perceptible shift of student orientation toward graduate work (Ref. D-7, p. 217). Furthermore, the data from the Industry-Government Survey showed that engineers in practice have a high interest in graduate study, and 80% of the bachelor's degree engineers stated that if they had their education to do over again, they would go on to graduate work (see Fig. B-5, Part B). Also, the Survey showed that engineering graduates in recent years have been given higher levels of technical responsibility in their first jobs (see Ref. D-8, Fig. 8, p. 242). This is consistent with some of the results of the Institutional Reports, which disclosed that engineering faculty foresee an increase in both the technical and social roles of engineers in society (see Figs. B-3 and B-4 of Part B). All of these considerations conform to what might be expected as engineering education gives greater emphasis to graduate study.

The growth phenomena described in this section are the key to understanding the changes in attitudes now taking place. *They show that engineering education is growing as part of a nationwide expansion in higher education. There are long-term social forces at work that result in higher educational desires and plans on the part of individuals, irrespective of specific technological needs. As a result, engineering students are becoming increasingly motivated toward more advanced levels of education. The Goals Committee endorses this trend as consistent with the needs of society and the engineering profession.*

### Projections

It undoubtedly is an appropriate national goal for the educational system to continue to grow in response to the changing conditions already mentioned. However, we must prepare adequately for this growth and think constructively about meeting the needs that it requires. In attempting to project the growth (and hence the needs) into the future, there are both long-term and short-term factors to be considered. The long-term effects are portrayed in Fig. D-2, described previously, and the short-term effects are given in Fig. D-3. This latter graph shows the recent degree output (since 1949) in engineering for bachelor's, master's, engineer,* and doctor's degrees. All of the curves begin with the above-normal bulges that followed World War II, and which are seen also in Fig. D-2. Included in Fig. D-3 are the long-range trend lines from the earlier figure. Also included are recent forecasts made by the Office of Education, shown by small triangles in the figure. Their projections of bachelor's degrees (from Ref. D-9) extend from 1967 to 1975 and those for master's and doctor's degrees are given for 1976 only (Ref. D-10). (Note: Figures D-2 and D-3 are based upon degree data for all institutions awarding engineering degrees, whether or not their curricula are accredited by ECPD.)

*A reasonable estimate for 1978 is about 50,000 bachelor's degrees, 32,000 master's degrees, 8,000 doctorates, and 400 engineer degrees. This estimate means that two out of three bachelor's graduates will go on to a master's degree, and about one in seven will go on to a doctorate.*

In 1962 the President's Science Advisory Committee (PSAC) set goals for doctor's degrees which indicated about 2,250 engineering doctorates would be needed in 1970 (see Ref. D-2). At that time this goal, which represented a doubling of the 1962 doctoral output, seemed very high. Remarkably, the PSAC goal for 1970 was actually exceeded in 1966 when 2,292 doctor's degrees were awarded in engineering.

Post-doctoral educational experience is probably increasing also, although no quantitative data were sought during this study. This sort of experience has been increasingly provided in the various scientific fields such as biology and chemistry, largely as specific preparation for research careers—an extension of the research apprenticeship aspect of the doctoral studies. For those doctoral engineers definitely planning on research as a career, the post-doctoral year (or more) may become a noticeable activity in another decade or two.

The growing importance of graduate study in engineering can also be seen in the graph showing master's degrees as a percent of bachelor's degrees (Fig. D-4). For the purpose of calculating the percentages shown in this figure, the number of master's degrees for each year was divided by the number of bachelor's degrees for the preceding year. Of course, many master's degrees are earned more than one year after the bachelor's degree. If this were taken into account, the percentages shown on the graph would become slightly higher because the number of degrees has been generally increasing.

The graph shows that a rapidly increasing fraction of engineering students with bachelor's degrees go on to obtain master's degrees. Specifically, this fraction has increased from about 10% to over 40% in only 15 years. However, the trend is not just a short-term effect, but has actually been going on since the turn of the century, when the fraction was about 1 in 100, or 1 percent. A reasonable extrapolation suggests that by 1970 about 50% of engineering bachelor's degree graduates will be going on for master's degrees, and by 1980

* Engineer degrees are described in Section 6.

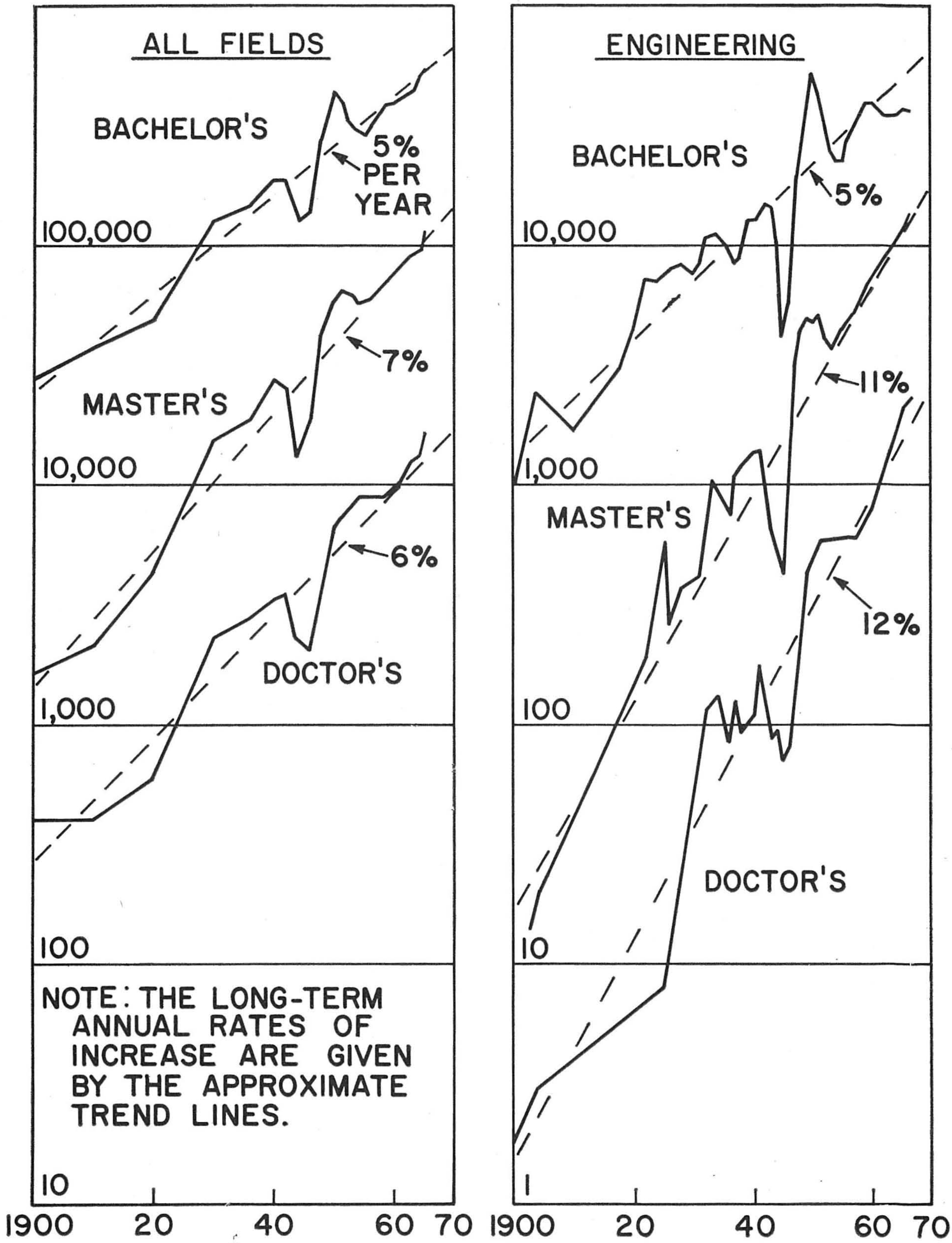



Figure D-2. Degrees awarded in the U.S. (1900 to 1966).

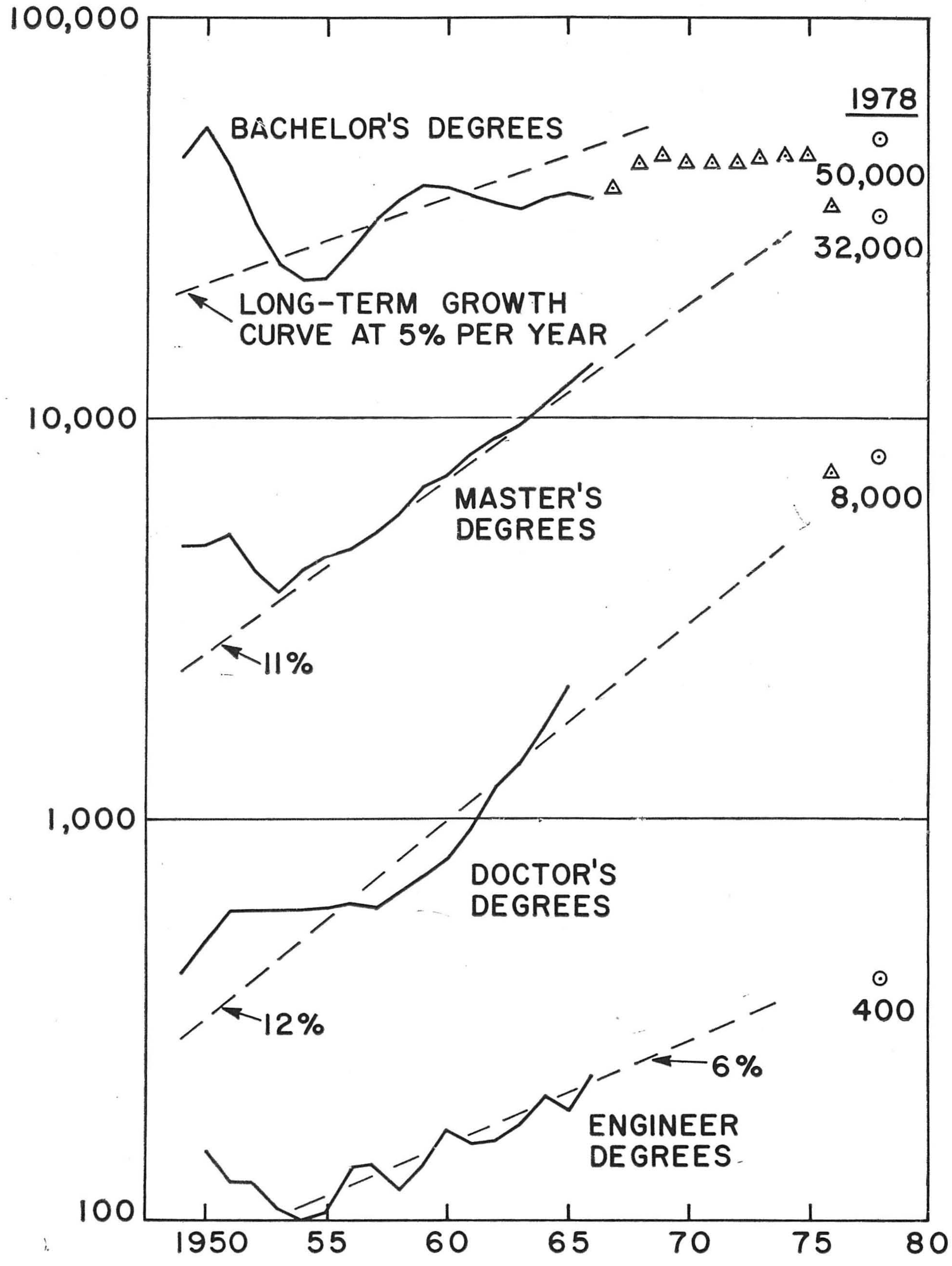



Figure D-3. Engineering degrees in the U.S. with projections. (Note: Triangles represent Office of Education projections; circles and accompanying numbers represent Goals predictions for 1978.)

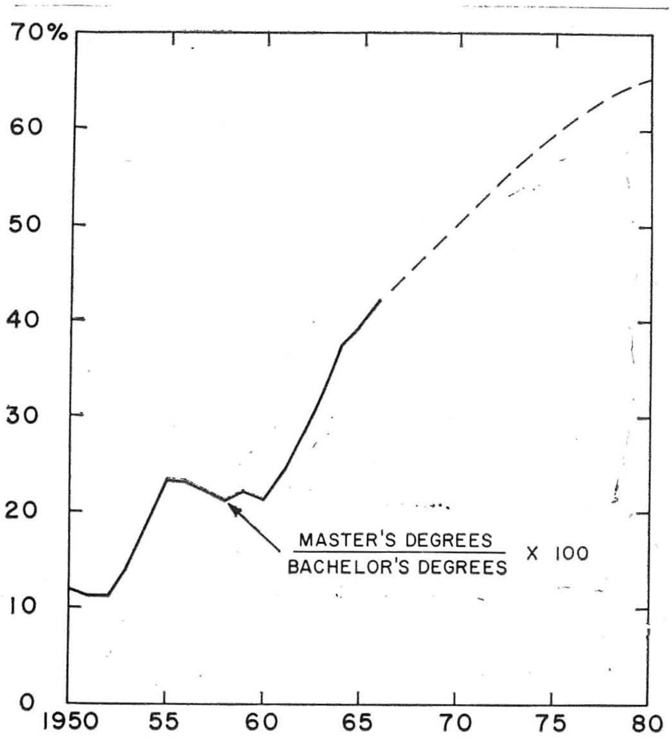



Figure D-4. Master's degrees as a percent of bachelor's degrees for the preceding year (engineering only) with projection to 1980.

about two-thirds will do so. The rate of increase can be expected to diminish as the percentage reaches higher levels. A recent report of the Engineering Manpower Commission gives the placement status of engineering bachelor's graduates and shows that the percentage going on *directly* to graduate study almost doubled in a six-year period (25% in 1967, versus 14% in 1961). This phenomenon is consonant with the general tendencies for higher levels of education that have already been described for the nation as a whole, and which are due to social forces of a very fundamental nature.

*It is the recommendation of the Goals Committee that the trends toward higher levels of education in engineering be encouraged, and that recognition be given now to the challenges implied in the numerical forecasts for 1978.*

### Maintenance of Quality

During the discussions of the Preliminary Report many groups severely criticized the trend toward more master's degrees on the basis that it will result in a lowering of standards because of the larger numbers who continue on for this degree. However, history shows us otherwise, because *there has been no demonstrable loss of quality in graduate work as the percentage going on for master's degrees has risen from 10% to over 40%*. We feel that this trend can safely continue and that the engineering profession will be upgraded as a result. (It is worth noting at this point that engineering faculty stated almost unanimously that their admission standards for graduate work have been rising in recent years; see Sect. 8.) Fortunately, evidence exists that an increasing proportion of highly talented individuals are entering engineering and also planning to undertake graduate study (see Part B, Sect. 5). An increase in educational attainment has been occurring generally in the United States, not only in engineering. As mentioned previously, in 1966 only 10% of all Americans 25 years old and over had completed four years of college or more. Approximately twenty years ago (in 1947), the comparable figure was 5%. This appears to be a desirable trend, and it does not seem reasonable to deplore it on the grounds that we may be lowering the standards of education.

*There is abundant evidence that many more persons can be educated to higher levels generally without loss of quality,* and presumably the same is true for engineering as for all fields. Fig. D-5 gives the relative numbers of persons in a given age group who reach various educational levels (Ref. D-11, pp. 144-145). The

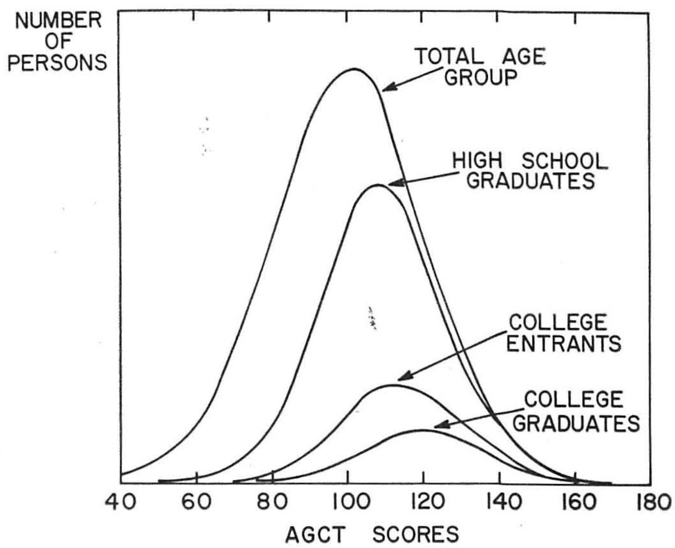



Figure D-5. Distribution of AGCT scores for persons in a given age group who reach various educational levels.

abscissa is the intelligence level as measured by scores on the Army General Classification Test (AGCT). The scores are normalized so that the average person in the total population has a score of 100. The curves show the increasing selection as people move to higher educational levels, but it also shows that at the college graduation level there is a large reservoir of persons with an adequate intellectual capacity who either do not enter or do not graduate from college. If we assume that a score of 110 is the minimum for college, there are three other persons with this same score or higher who have graduated from high school but either do not go to college or do not graduate from college. There is thus a significant underdevelopment of one of our most important natural resources, namely, human talent (see also Ref. D-12, p. 126).

Even for the doctoral level there is no shortage of intellectually qualified persons. Figure D-6 gives the distribution of AGCT scores for the 1958 doctorate population and also for all persons of the same age group in the general population (Ref. D-13, p. 681). Note that the curves are drawn to a logarithmic vertical scale because of the great difference in numbers of persons. The figure shows that in general the doctorate

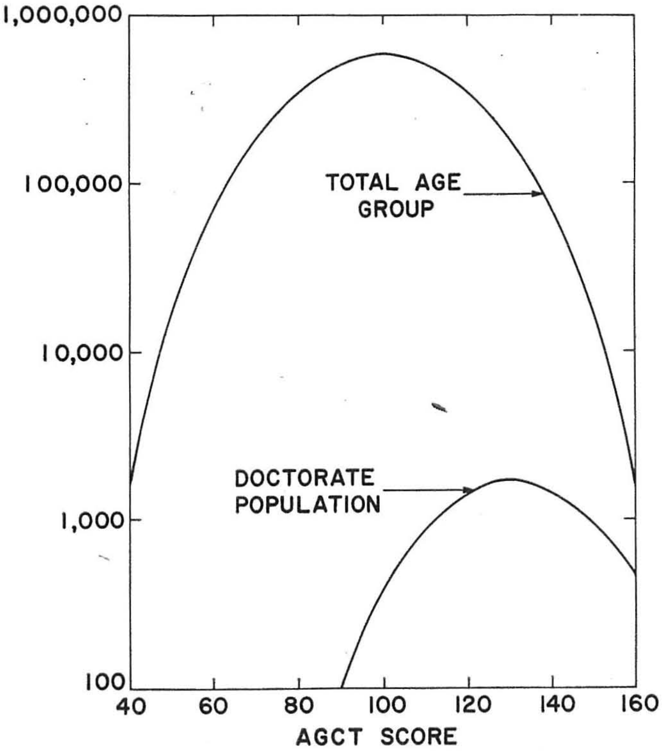



Figure D-6. Distribution of AGCT scores for 1958 doctorate population (note log scale).

population (average score 130) has a higher intelligence level than the same age group from the general population (average score 100), as would be expected. But it also can be seen that at all levels there is a large reservoir of persons capable of doctorate training. At a score of 130, which is the average for the doctorate population, only one person in 100 continued his education to the doctoral level. The percent of persons trained to the doctoral level for various AGCT scores is plotted in Fig. D-7, and it can be seen that even at the "genius" level (AGCT 170) only one out of five qualified persons completes the doctorate. Thus, there is a large reservoir

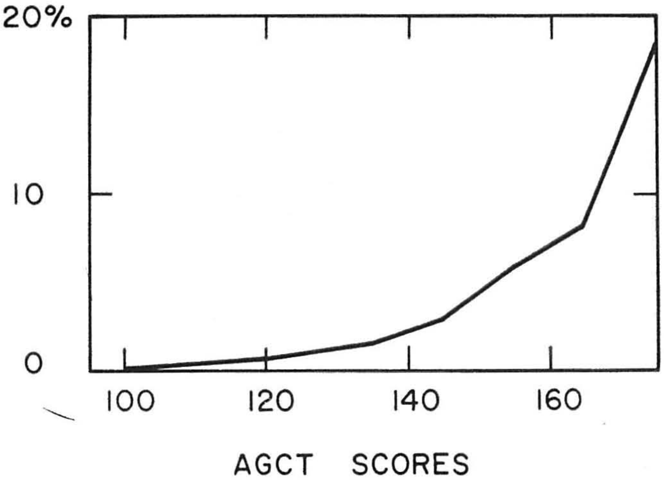



Figure D-7. Percent of general population that attains a doctoral degree.

of underdeveloped talent available for doctoral study, irrespective of the level of ability that is assumed to be required for doctoral training (Refs. D-13 and D-14). Admittedly, the AGCT score may not include all necessary attributes, such as creativity. Nevertheless, there exists a national human resource that can be developed to a greater extent. This additional development is an important goal toward which we should be working, and many authors have discussed the significance of the problem (see Refs. D-11 to D-14).

*With respect to engineering education at advanced levels, it is recommended that we continue to develop this national resource of able students as increasingly they seek advanced degrees, while at the same time ensuring that quality is maintained by encouraging only those students who possess adequate ability.*

### *New Institutions*

Concurrent with the increased emphasis on graduate study in engineering and the resulting growth in degrees, the number of institutions awarding graduate degrees has been increasing. This change is shown for doctor's degrees in engineering in Fig. D-8. It can be seen from the graph that the number of institutions

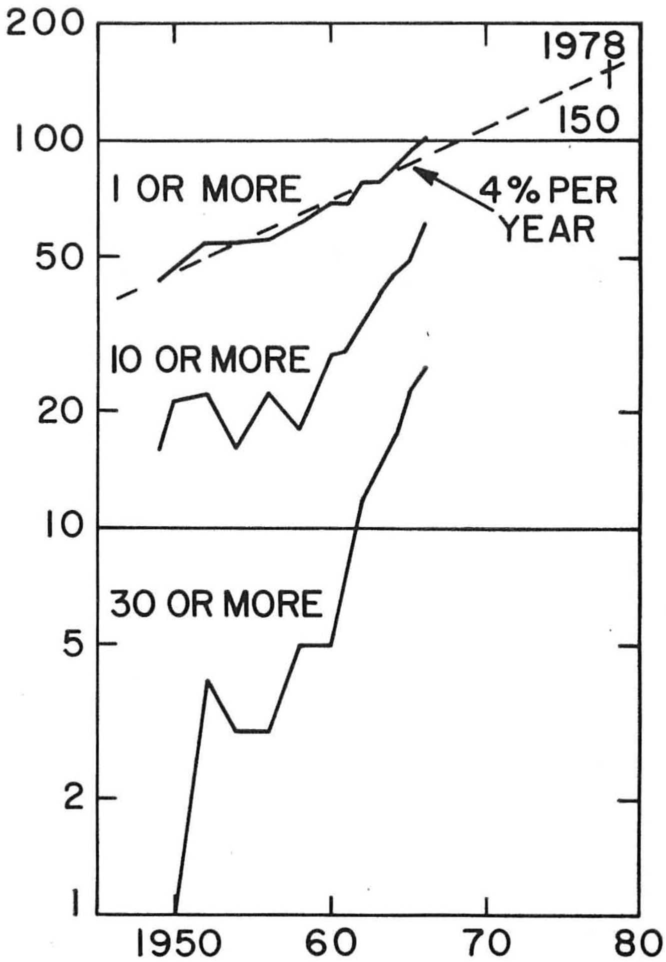



Figure D-8. Number of institutions awarding various numbers of doctor's degrees in engineering.

awarding at least one doctorate per year more than doubled in 16 years (101 institutions in 1966 versus 46 in 1950). The average rate of increase is 4% per year, which is less than the growth rate for doctor's degrees. Thus, it is clear that the growth in doctoral output is being accomplished more by increases in the sizes of existing doctoral schools than by the addition of new schools. This conclusion is verified by the last two curves in the figure, which show the faster increase in number of institutions awarding larger numbers of degrees.

*Since 1950 about 55 new schools have given one or more doctoral degrees annually. If this rate of increase continues, there will be 150 schools giving doctoral degrees in 1978 (see Fig. D-8).* Growth in the number of doctoral institutions seems to be a normal phenomenon. Quality has been maintained in the past as new schools have entered upon graduate education, and it should be possible for this to continue.

Existing doctoral schools have been increasing in size for many years, as shown for a few schools in Table D-1.

TABLE D-1

ANNUAL NUMBER OF DOCTOR'S DEGREES (AVERAGED OVER PERIOD INDICATED)

| Institutions | 1936-42 | 1950-56 | 1958-62 | 1964 | 1966 |
|---|---|---|---|---|---|
| MIT | 13 | 68 | 95 | 150 | 173 |
| Univ. of Calif. (Berkeley) | 1 | 17 | 32 | 68 | 114 |
| Univ. of Illinois | 4 | 39 | 64 | 131 | 114 |
| Stanford | 2 | 22 | 47 | 94 | 106 |
| Purdue | 1 | 34 | 45 | 83 | 95 |
| Univ. of Michigan | 12 | 30 | 45 | 75 | 74 |

This table gives the growth in average number of doctor's degrees awarded annually during the past 30 years by six schools which in 1966 were the largest awarder's of doctor's degrees. Some of these schools have developed from a stage where they awarded only one or two doctor's degrees each year; all have increased tremendously in size. The figures serve to emphasize that those institutions now having well-established doctoral programs were not always in that situation. Instead, each school at some time in its history made a beginning, and programs that once handled only a few doctoral students per year have been developed to the stage where they now accommodate much larger numbers.* *Thus, new doctoral institutions should continue to arise, provided that each establishes for itself adequate plans and policies.*

Data pertaining to growth in the number of institutions awarding master's degrees in engineering is shown in Fig. D-9. The same general phenomenon exists as for doctor's degrees, except that the annual rate of increase for schools awarding one or more degrees is less (156 schools in 1966 versus 102 schools in 1950). At the present rate of growth, there will be 200 schools awarding master's degrees in 1978. A similar projection for bachelor's institutions indicates that slightly more than 200 schools will be awarding bachelor's degrees in engineering in 1978. Thus, we can expect that most baccalaureate institutions will also have master's programs.

* The nature of this process was studied in detail in a group of engineering graduate schools, and the findings are reported in Section 11.

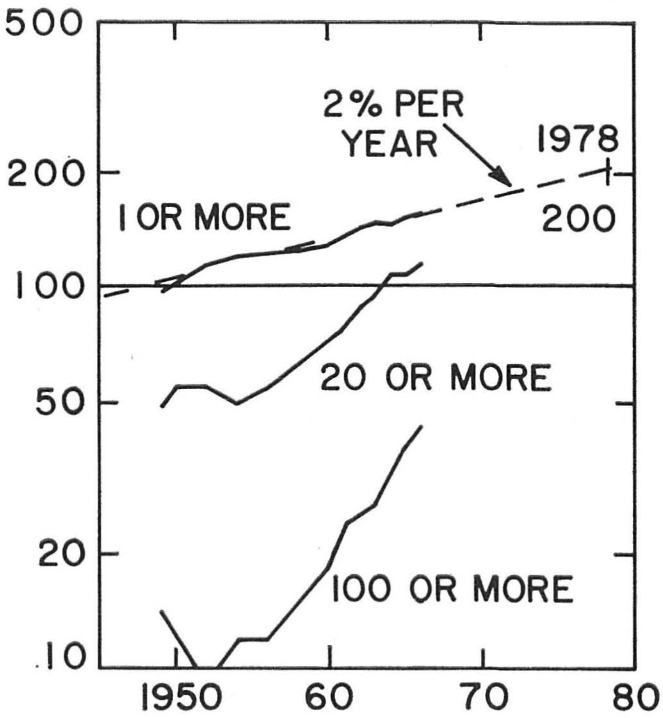



Figure D-9. Number of institutions awarding various numbers of master's degrees in engineering.

*It is recommended that the formation of new graduate engineering schools continue but with emphasis upon maintaining high standards.*

*Distribution Phenomena*

Another aspect of graduate education is the concentration of the majority of students in a relatively few institutions—and a misconception that these "favored" institutions constitute a permanent bloc. One way of examining this concern is to look at the number of institutions awarding a given percentage of the doctor's degrees (see Table D-2). The table shows clearly that the number of schools in each percentage bracket is not static but is continually increasing. Thus, whereas six institutions produced 50% of the degrees in 1936-42, it required ten institutions to do this in 1958-62 and fifteen institutions in 1966. The number of institutions

TABLE D-2

NUMBER OF INSTITUTIONS AWARDING THE GIVEN PERCENTAGE OF DOCTOR'S DEGREES IN YEARS SHOWN

| Percent of Total Degrees | 1936-42 | 1950-56 | 1958-62 | 1964 | 1966 |
|---|---|---|---|---|---|
| 25% | 2 | 3 | 4 | 4 | 5 |
| 50% | 6 | 10 | 10 | 12 | 15 |
| 75% | 12 | 20 | 23 | 27 | 33 |
| 100% | 39 | 71 | 81 | 85 | 101 |

required to produce 25% of the degrees is a smaller number, and hence does not appear to be changing so noticeably. However, it can be seen that this number has more then doubled since 1936-42 (from 2 to 5) as has also the 50% number (from 6 to 15).

Perhaps even more important than the increase in numbers of schools is the fact that individual institutions alter their relative positions within the framework of the total national activity. Some historical changes of this kind are portrayed in Table D-3, which gives the degree-ranking of eleven schools, selected because they were among the largest six schools in awarding doctor's degrees during at least one of the time periods shown in the table. The figures show clearly that significant mobility exists in the degree-ranking of the institutions. Some institutions have apparently made deliberate efforts to increase the extent of their graduate work, while others have concentrated upon improving their activities within a given framework of size. Whether such increases and changes are to be made is, of course, a matter for each institution to decide. Even those schools which have elected to grow quite large have maintained quality; indeed they have been rated exceptionally high in a report of the American Council of Education (see Ref. D-15 and also Sect. 11).

TABLE D-3
RANK IN NUMBER OF DOCTOR'S DEGREES AWARDED

| Institution | 1936-42 | 1950-56 | 1958-62 | 1964 | 1966 |
|---|---|---|---|---|---|
| MIT | 1 | 1 | 1 | 1 | 1 |
| Univ. of Calif. (Berkeley) | 17 | 11 | 6 | 6 | 2 |
| Univ. of Illinois | 7 | 2 | 2 | 2 | 3 |
| Stanford | 13 | 7 | 3 | 3 | 4 |
| Purdue | 22 | 3 | 5 | 4 | 5 |
| Univ. of Michigan | 2 | 4 | 4 | 5 | 6 |
| Cornell | 4 | 10 | 12 | 20 | 9 |
| Univ. of Minnesota | 6 | 15 | 17 | 18 | 13 |
| Calif. Inst. of Tech. | 3 | 5 | 11 | 8 | 16 |
| Univ. of Wisconsin | 9 | 6 | 7 | 15 | 18 |
| Johns Hopkins | 5 | 17 | 22 | 41 | 41 |

The size distribution among the engineering schools at the doctor's, master's, and bachelor's levels is portrayed in Fig. D-10. Note the similarity in the distributions even though the numbers of degrees and institutions vary considerably. (See Appendices V, VI, VII, and VIII for a complete listing of schools awarding degrees in 1966.) A convenient measure of the distribution is the "50 percent index," which is the percent of the institutions providing 50% of the degrees. This index is approximately 21% for undergraduate degrees and 14% for graduate degrees. This apparent concentration of degrees is not a recent phenomenon, nor is it unique to engineering. It appears to be a natural characteristic of our society, in which it should be obvious that all schools are not the same size. The phenomenon is illustrated further in Fig. D-11, where all of the items in the table have distribution curves contained within the shaded area in the graph. The table shows that 50

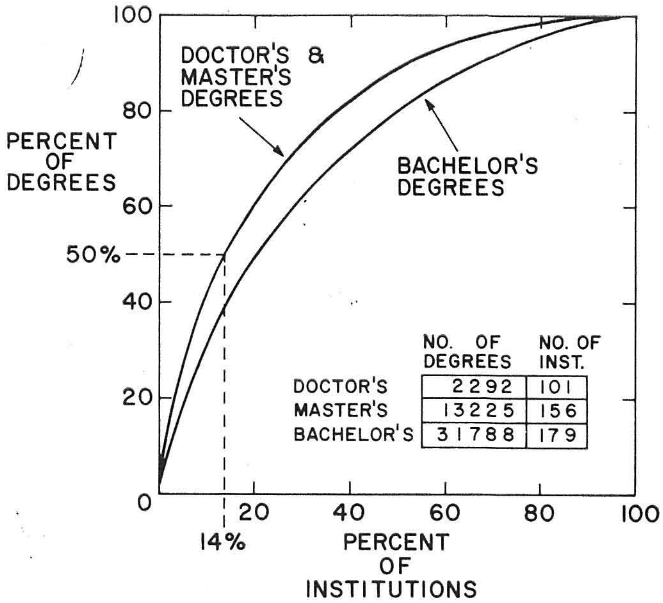
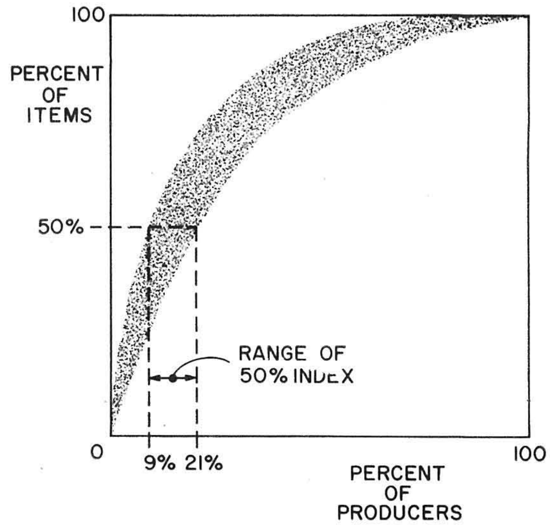



Figure D-10. Distribution of degrees in engineering (1966) for institutions with at least one ECPD-accredited curriculum. (Note that 50 percent of the doctor's and master's degrees are awarded by 14 percent of the institutions.)




| | FIFTY PERCENT INDEX |
|---|---|
| BACHELORS DEGREES IN ENGINEERING (1958-62) | 21% |
| BACHELORS DEGREES IN ENGINEERING (1918) | 15% |
| DOCTORS DEGREES IN ENGINEERING (1936-42) | 13% |
| DOCTORS DEGREES IN PHYSICS (1950-59) | 16% |
| DOCTORS DEGREES IN ALL FIELDS (1959-60) | 9% |
| RESEARCH EXPENDITURES IN ENGINEERING (1962) | 11% |
| NSF RESEARCH GRANTS IN ENGINEERING (FY63) | 14% |
| NSF GRADUATE FELLOWSHIPS IN ENGINEERING (FIRST YEAR; FELLOWSHIP INSTITUTION; FY64) | 11% |
| POPULATION OF 225 LARGEST U.S. CITIES (1960) | 10% |

Figure D-11. Range of distribution curves for various items and the 50 percent index. (The index is the percent of "producers" providing 50 percent of the items.)

percent of any of the items are produced by a comparatively small fraction of the producers (see Refs. D-2 and D-3). Many other activities in our national life, such as the size distribution of business firms, could have been included in Fig. D-11.

*The important thing to realize is that the distribution phenomenon is a natural one that has not been influenced, for example, by recent federal support, as some people seem to think.*

*Thus, it can be seen that individual institutions can operate successfully at any size level consistent with the institution's resources and aspirations, with quality always as an underlying requisite. Furthermore, the public should understand that in a democratic society the basic concern should be for equality of opportunity—in the context that graduate engineering schools should be free to determine their size and scope—with the usual democratic outcome that different institutions will use this freedom differently, and that this diversity should be encouraged rather than criticized as inequality.*

# 2. CHARACTERISTICS OF ENGINEERS WITH ADVANCED DEGREES

The purpose of this section is to point out some features of engineers who have gone on for advanced degrees, and to make some comparisons between them and those who completed only the basic bachelor's degree. It is important for engineering educators to know as much as possible about engineering graduates in order to better advise and instruct students. Much useful information about the profession has been obtained from the Industry-Government Survey and from the Institutional Reports, and can be found in Part B, and some has been published elsewhere (Refs. D-7 and D-8).

### *Function of Engineers With Advanced Degrees*

The relative numbers of engineers engaged in various functions at the time of the Industry-Government Survey (1964) were shown previously in Fig. C-1. The percentages are shown separately for engineers with bachelor's, master's, and doctor's degrees, and it must be kept in mind that the total numbers in each of these three categories are quite different. The figure shows that a substantial fraction of each degree group is working in management and an even larger group is in development. Thus, doctorates are about as likely to be working in engineering development as are bachelor's holders, a fact which has implications for educational programs. By contrast—and as would be expected—a much larger fraction of the doctorates are in research than in the combined functions of design, operations, production, etc. (These functions are collected together in the figure because they are similar in having the smallest fraction for doctorates and the largest fraction for bachelor's degree holders.)

From Fig. C-1 it might appear that the number of engineers engaged in research is large, but it must be remembered that the number of doctoral engineers is very small compared to the others. Our forecast for 1978 is that about 16% of the bachelor's degree recipients will go on to doctorates. If present trends continue, about one-third of those will go into teaching (see Section 5), and of the remainder about half may be in research as at present (see Fig. C-1). Thus, only about 5% of the engineering bachelors can be expected to become doctorates working in research in industry or government. Research should properly be regarded as an important part of the engineering functional spectrum, and a small percentage of engineers must always be engaged in this function.

The shift in function that occurs between the first job and later ones was determined in the Industry-Government Survey, and is shown in Fig. D-12. A larger fraction (61%) of doctoral graduates began work

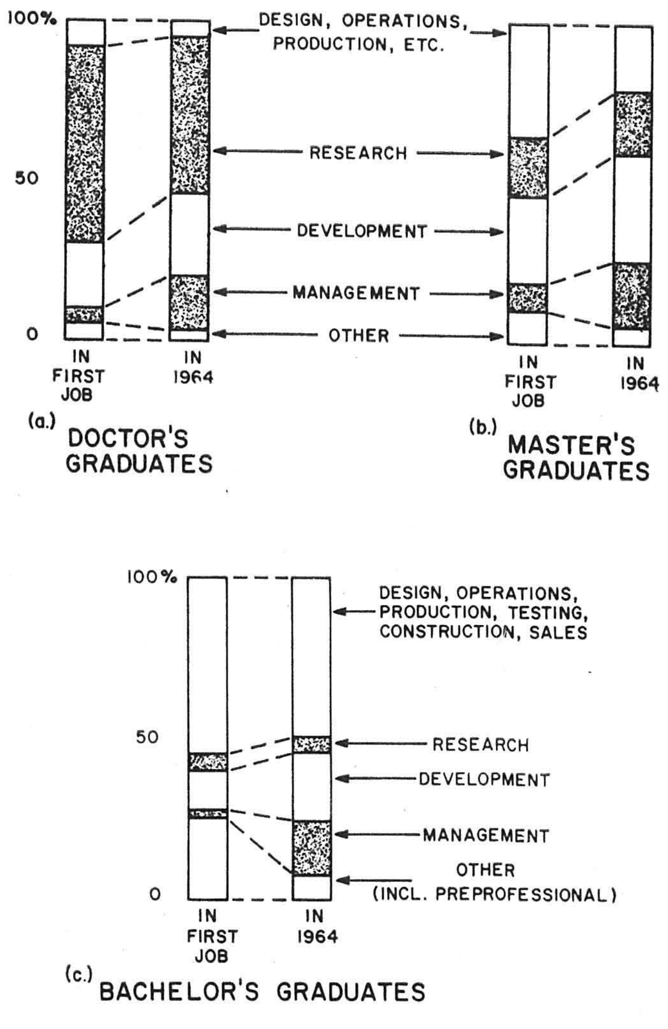



Figure D-12. Changes in functions between first job and job in 1964.

in research, but this number decreased later to 48%. The number in development increased from 22% to 27%, and the number in management increased markedly from 4% to 16%. For the master's graduates there was a noticeable decrease in the number in design, operations, etc., accompanied by an increase of those engaged in development and management. Similar changes occurred with the bachelor's engineers, with the addition that the number engaged initially in pre-professional work obviously decreased greatly.

The number of engineers working in industry or government who were engaged in research and development at the time of their first jobs shows an interesting increase over the years, as portrayed in Fig. D-13, which is taken from Ref. D-8. It is seen that the percent of doctoral engineers in industry or government who are now taking their initial employment in research and development is about 90%; for master's and bachelor's graduates it is 60% and 30%, respectively. All of these figures represent increases as compared with twenty years ago. Thus, it is clear that there is a growing research and development function in engineering and that it is associated not only with doctoral degree engineers but with bachelor's and master's degree holders as well.

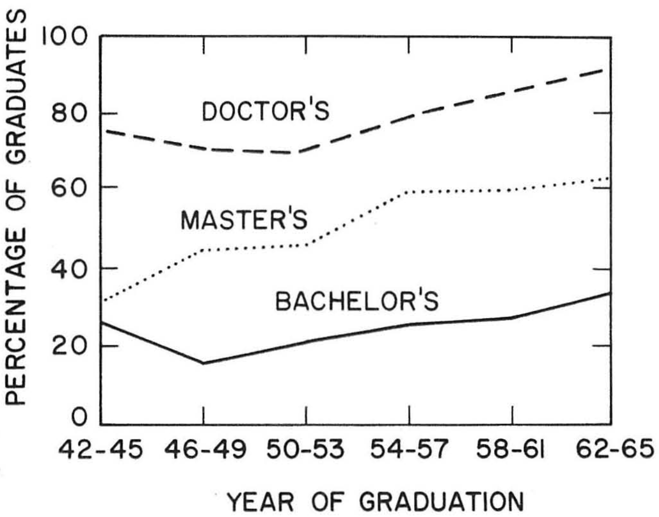



Figure D-13. Percentage of bachelor's, master's, and doctoral engineers engaged in research and development in their first job by year of graduation.

In summary, we can draw several conclusions from the data given above and obtained from the Industry-Government Survey:

*Engineers with graduate degrees are found in all of the engineering functions, including management, development, and research.*

*Research is an important part of engineering, but only about 5% of engineering bachelors will become doctorates working in research in industry or government. The percent of engineers at all levels engaged in research and development is steadily rising.*

*Engineers at all levels move into management functions with the passage of time, although the total percent in management is not large (about 17%). Doctoral engineers are just as likely to become managers as are bachelor's engineers.*

#### Comparisons Between Industry and Government

In the Industry-Government Survey the division of engineers between government and private industry was about the same for the different degree levels, as shown earlier in Fig. C-2a. Thus, it appears that *the demand for advanced-degree engineers, as compared to bachelor's engineers, is about the same in both industry and government.*

Of those engineers working in private industry the proportion working on government projects is higher for the holders of advanced degrees (see Fig. C-2b), suggesting that the government as a customer of private industry calls for more advanced products and services than does the commercial market.

#### Professional Attributes

It is important to recognize the extent to which engineers with advanced degrees function as members of their technical profession. Some results from the Industry-Government Survey on this subject are shown in Fig. D-14. The figure shows that the graduate degree holders, doctoral engineers in particular, are more active technically and professionally than the baccalaureate engineers, as measured by several recognized attributes of a professional person, including subscribing to engineering periodicals, reading new technical books, attending meetings, writing and presenting papers, etc.

Another dimension of a profession is society membership, and the percentage of engineers belonging to professional societies is shown in Fig. D-15. Holders of advanced degrees belong to more technical societies than do the bachelor's engineers.

Still another consideration of professionalism is the extent to which engineers become registered as Professional Engineers. Of the engineers in the Survey, 26%

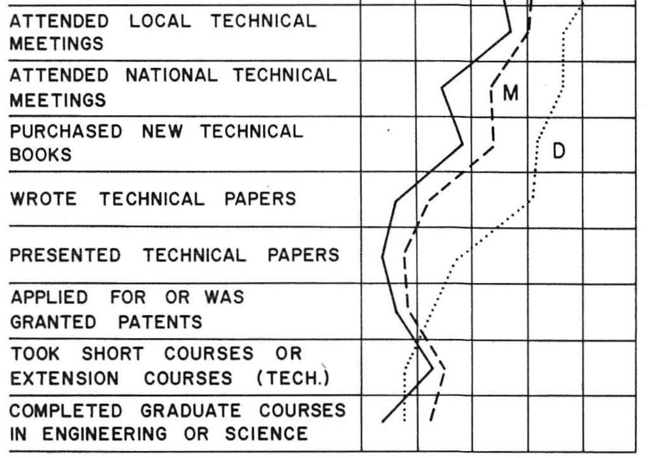



Figure D-14. Percentage of bachelor's, master's, and doctoral engineers engaged in various professional activities during the previous year.

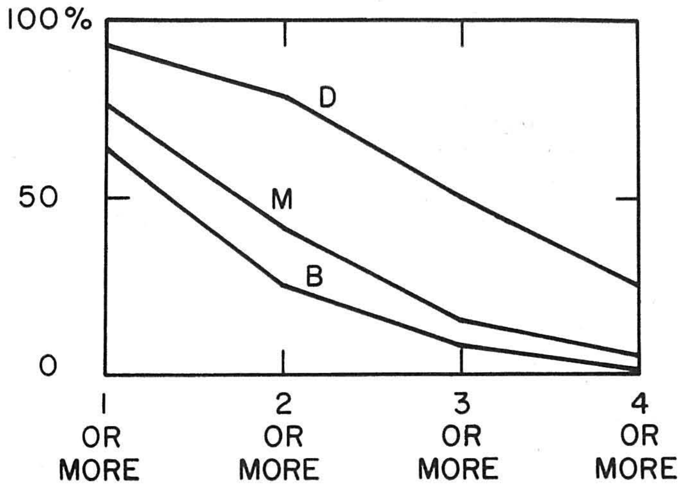



Figure D-15. Percentage of bachelor's, master's, and doctoral engineers belonging to various numbers of professional and scientific societies.

of those with bachelor's degrees are registered P.E.'s. The figures for master's and doctor's degree engineers are 30% and 22%, respectively. Thus, the master's engineers are more likely to be registered than are the bachelor's engineers, in spite of the fact that a higher percent of bachelor's engineers are engaged in those activities where registration is apt to be important (design, etc.). Although doctoral engineers have the least need to be registered, because such a high percent of them are involved in research, the percentage of them who do attain registration is almost as high as in the bachelor's group. (For more detail on the registration status of engineers in the Survey, see Ref. D-8, p. 250.)

The conclusion to be drawn from these data on the dimensions of professionalism can be simply stated:

*Advanced-degree engineers function more fully as members of a technical profession than do engineers possessing only the bachelor's degree.*

This conclusion is an important one, because there is a widely-held notion (it appeared repeatedly during the discussions of the Preliminary Report) that the bachelor's degree engineers are the "real engineers." While this may have been true in the past, we are now into the era where the "real engineers" will be largely those with graduate degrees, and one can expect this to become even more so in the future. Of course, it must be recognized not only here, but in other parts of this section, that the different characteristics of engineers are not necessarily the *result* of graduate education, but they may represent inherent characteristics of that group of engineers who elected to undertake, and who succeeded in, graduate study.

### Professional Values

As part of the Industry-Government Survey, a study was made of the attitudes of engineers toward certain goals and values which affect their work. While the reader should examine Ref. D-8 for more detailed information, it is perhaps of interest to report here some of the overall conclusions. The importance of publishing, contact with colleagues, contributions to society, contributions to scientific knowledge, influence over technical projects, and the opportunities to keep up to date by using libraries and seminars were greatest with the doctoral engineers, next with the master's engineers, and least important to the bachelor's engineers. On the other hand, the importance of moving into management, career security, and advancement, and the opportunity to help others were greatest with the bachelor's engineers, next with the master's engineers, and least important to the doctoral engineers. Finally, each group assigned its highest values to work opportunities such as challenge, innovation, and keeping abreast of new developments.

### Attitudes Toward Advanced Study

The best indication of the attitudes held by today's engineers concerning graduate study can be found in the growth curves presented in Section 1. The growing number who take graduate work is practical evidence that graduate work is much sought after.

In addition, the attitudes of engineers toward graduate study were explored in several ways by the Industry-Government Survey. One question asked was, "If you had your education to do over again, would you go on to graduate work?" Not surprisingly, 99% of the persons with master's degree and 98% of the persons with doctor's degrees answered "yes" to this question (see Fig. B-5, Part B). More important, however, was the fact that 80% of the bachelor's engineers answered "yes." *Thus, it appears that those who took graduate study are satisfied that they did so, and those who didn't take graduate work would like to have done so.*

In another question the engineers were asked whether they agreed or disagreed with the statement, "In my field, a bachelor's degree is sufficient preparation for most work, and graduate study is not needed." In response to this question, 65% of the bachelor's engineers agreed with it. Comparison of the response to this question with the earlier one suggests that while bachelor's engineers would like to have taken advanced work, they will not admit that in their present work it is an absolute necessity. To say otherwise would imply that they were inadequately trained for their jobs. Perhaps the strong wish for graduate work that was seen in the earlier question arises from a desire to be doing a higher level of work, rather than from any feeling that it would be helpful on the immediate job. Perhaps also they have not considered the question of their own ability to have succeeded at graduate study, but have perceived only the benefits occurring to their colleagues who did go on successfully. To this same question of the need for only a bachelor's degree for work in their field, only 32% of the master's engineers and 14% of the doctor's engineers agreed. *Thus, the overwhelming majority of persons with master's and doctor's degrees feel that advanced work is needed and that a bachelor's degree is not sufficient.*

Another indicator of engineering attitude toward graduate study came from a question in the pre-test of the Industry-Government Survey, where in addition to the question as to *minimum* level of formal education the engineers were also asked what they regarded as the *optimum* level. Whereas approximately 80% in the

BS-MS group said that the bachelor's degree was a minimum, 53% said the master's degree would be optimum.

When asked as to whether graduate work was needed with an emphasis on management, the percentages of agreement were as follows: bachelor's engineers, 63%; master's engineers, 53%; and doctoral engineers, 26%. When asked as to whether graduate work was needed with an emphasis on science and mathematics, the percentages of agreement were: bachelor's 41%; master's, 65%; doctor's, 89%. Thus a clear pattern emerges *with the bachelor's group being more interested in the availability of management training at the graduate level and the doctor's group being more interested in science and mathematics.*

### Employer Attitudes

The attitudes of engineers toward advanced degrees is certainly influenced to some extent by what they perceive to be the attitudes of their present or prospective employers. This is not the major motivation, however, since only a minority (23%) of the engineers surveyed felt that their employer gave "much" encouragement or rewarded often (24%) the completion of advanced-degree work. Interestingly, the personnel representatives of these same employers perceived these attitudes as more prevalent: 42% and 44%, respectively.

Substantial differences exist between industry groups as to attitudes on advanced-degree work as shown in Fig. D-16 and also in Fig. 4 of Ref. D-16. It is clear that the majority of employers give "some" or "much" encouragement rather than "none," but this is certainly not the prime force behind the growth in advanced-degree education in the U.S. Rather, as stated before, it is more the aspiration of individual students for higher levels of learning and professional competence.

| INDUSTRY | PERCENTAGE OF RESPONDENTS REPORTING ENCOURAGEMENT TO TAKE ADVANCED DEGREE WORK | | |
|---|---|---|---|
| | NONE | SOME | MUCH |
| RESEARCH & DEVELOPMENT | 5 | 46 | 49 |
| AERO-SPACE | 7 | 56 | 37 |
| ELECTRICAL EQUIPMENT | 15 | 49 | 36 |
| METALS, ORDINANCE | 30 | 49 | 21 |
| MACHINERY | 13 | 64 | 24 |
| MISCELLANEOUS MANUFACTURING | 27 | 55 | 18 |
| CHEMICALS, PETROLEUM | 28 | 54 | 18 |
| ENGINEERING & ARCHITECTURE | 39 | 49 | 13 |
| FEDERAL GOVERNMENT | 36 | 51 | 13 |
| UTILITIES | 21 | 66 | 13 |
| LOCAL GOVERNMENT | 48 | 43 | 9 |
| CONSTRUCTION | 60 | 38 | 3 |

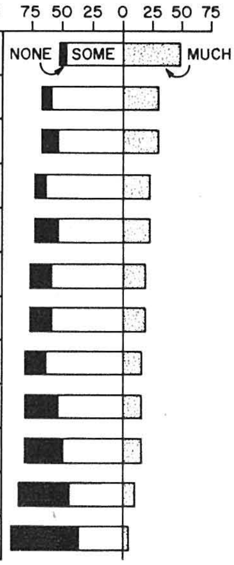



Figure D-16. Percentage of graduates by industry who reported encouragement for advanced-degree work.

### Time of Decision to Take Graduate Work

An interesting paradox exists regarding graduate work in engineering. On one hand we have the large number who are taking graduate work (see Section 1) and the almost unanimous endorsement (over 80%, as pointed out above) of graduate work on the part of practicing engineers, and on the other hand we have a widely held belief that a bachelor's degree is sufficient preparation for engineering work. Students apparently enter college with the latter idea, and only later do they discover that they really should go on for at least a master's degree. Only 15% of the engineers in industry with advanced degrees decided before the senior year to take graduate work. This situation has not improved with time (see Fig. D-17), even though increasing numbers of students finally decide in favor of graduate study. Even more surprising, only 45% of the engineers decided before receiving the bachelor's degree to take graduate work; thus, about 55% made no plan until *after graduation* to take graduate work. As a result, it has been typical of students entering engineering to make their initial plans only as far as the bachelor's degree. Then after obtaining employment and learning more about the profession, with its opportunities and challenges for engineers with advanced education, they raise their sights to the master's or doctor's level.

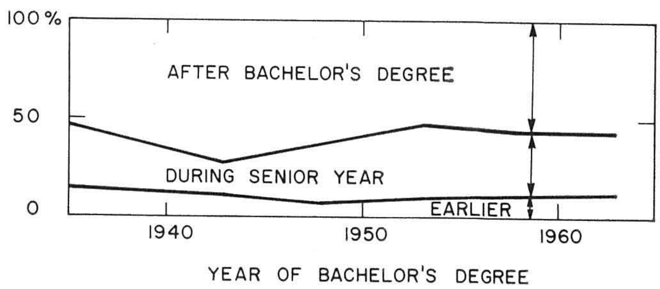



Figure D-17. Time of decision to take graduate work.

In view of the actual facts concerning the number of engineers who take graduate education, *it seems desirable for the profession to publicize more widely that graduate studies are a normal part of engineering education. The unreasonably restrictive conception that a bachelor's degree is sufficient preparation for most engineering work should not be perpetuated.*

### Conclusions

In this section we have emphasized that engineers seeking advanced degrees are not a small group with narrow interests centering on research, but rather that graduate-degree holders are performing in a major way as professionals within engineering. While these ideas may seem obvious to many, the unfortunate fact is that they are not well-known to the public, and even among engineering educators there is still a tendency to ignore them.

*Hence, it is recommended that the engineering profession recognize publicly and disseminate more widely the* *concept that graduate study and advanced degrees are an integral part of engineering education.*

*It is further recommended that engineering schools continue to provide advanced levels of education of high quality that prepare persons for all of the engineering functions, including design, development, management, research, etc. An individual school may wish to emphasize one or more of these functions, depending upon the kinds of faculty, students, and facilities which it has.*

*Finally, it is recommended that engineering faculty continue to instill in engineering students at all degree levels those professional attributes and values that are vital to the maintenance of a high standard of service to society.*

## 3. CHARACTERISTICS OF ADVANCED AND CONTINUING EDUCATION

### *Purposes and Patterns*

Engineering education beyond the first basic degree serves a variety of purposes or functions. By purpose is meant the objective of the student's particular educational endeavor, as distinct from the particular pattern or arrangement used to accomplish the purpose. The primary purposes or functions include: (1) *upgrading* a person's education (that is, pursuing an articulated formal program of study to raise the student's level of education); (2) *updating* a person's education (for instance, a person who received a bachelor's degree ten years ago may take course work to make his formal education comparable to that of a person receiving a bachelor's degree this year); (3) *diversifying* to new fields (a person educated in one field may seek to obtain some formal education in another field, but not necessarily at a higher degree level); and (4) *broadening* of a person's education (this refers to the addition of new and broader perspective in one's own field, such as the inclusion of financial, political, and social factors, but again without necessarily raising the academic level of the education).

Since there are many variations on the four categories of purposes given above, it is impossible to be completely logical and precise in defining them. However, these definitions can serve a useful role in clarifying certain issues and in distinguishing between types of programs. For example, it is useful to distinguish between *advanced degree education* and *continuing engineering studies,* even though the two are frequently intertwined. Advanced degree education is more concerned with the upgrading function than with the other functions. It usually refers to study in one's own field at progressively higher levels; specifically, it would not primarily emphasize the updating function. Continuing studies, on the other hand, will usually refer to programs of study that better equip a person for his work (whether it be in industry, teaching, research, etc.) through updating, diversifying, and broadening. Further discussion of continuing studies is contained in Sect. 13 and in the report of the Joint Advisory Committee (Ref. D-17).

Another feature of advanced-degree education is that it usually is *preparatory,* and is undertaken prior to embarking on a career at a new and higher level of performance. By contrast, continuing studies involve a more or less *continuous performance,* usually concurrent with employment.

Even within the upgrading function of advanced-degree education there may be functions of other kinds. Advanced *skills* are sometimes the goal, and these may be directed toward research, design, or other professional endeavors. Also of importance is the advancement of the student's self-reliance in *learning.*

With respect to the varied *patterns,* or structure, of advanced engineering education, it may be noted that graduate education is usually the undisputed province of the universities, which give recognition in the form of advanced academic degrees. However, continuing studies are facilitated not only by the universities, but also by industry, government, and professional or technical societies. The patterns for student participation in graduate education include: (1) full-time study on-campus, (2) part-time study on-campus accompanied by part-time employment on-campus, (3) part-time study on-campus with employment off-campus, and (4) part-time study off-campus; each of these will be considered in Section 10. Continuing studies are conducted principally through part-time study, either on or off-campus, with employment being off-campus. In the process of continuing studies the schools, industry, professional societies, and of course the individual himself, all have an important role. *As W. L. Everitt once phrased it, engineering is a "learning" profession.*

### *Types of Programs for Advanced Degrees*

The evidence presented in Section 2 clearly indicates that engineering education at the graduate level has successfully prepared students for diverse professional functions. *Thus, there is an obvious implication that such programs should allow for breadth as well as depth,* in the same way that undergraduate programs have traditionally done. There must be provision for some students to take advanced work in the humanities and social sciences, along with courses in engineering and the physical sciences. There must be provision for some students, let us say those interested in research, to pursue studies that are very advanced and very specialized in a narrow but well-defined area. There must be provision for students interested in engineering design work of a professional character to study subjects appropriate to this goal. And the list could be continued indefinitely because of the variety of purposes that must be served.

No school can be expected to offer a complete range of graduate programs but rather *each school must undertake to do that which it is best prepared to handle without loss of quality—depending on the faculty, students, and resources of the school.*

# 4. THE MASTER'S DEGREE

*Routes to the Master's Degree*

Programs at the master's level must be diverse enough to provide for a variety of career objectives on the part of the students, in addition to being flexible enough to accommodate the many varieties of previous preparation that students possess. There must be a diversity of routes by which engineering students enter and emerge from master's programs. The flow chart in Fig. D-18 depicts the important possibilities. The principal route at the present time is the uppermost one in the chart, wherein the typical engineering student follows a four-year undergraduate program in an engineering college. Of course, many students may leave the program at the end of four years, perhaps to continue their education through evening courses or perhaps to return to college at some future time. However, the expectation is that within ten years more than half of the students will continue to the master's level, as previously pointed out. Also, a few students will continue further with studies aimed at a professional career and receive either the engineer or the doctor's degree.

Students may transfer as undergraduates into engineering programs from other curricula or other colleges (such as the two-year community colleges), but in so doing they will presumably be required to make up all deficiences, so that by the time they receive a bachelor's degree they will have completed the same studies as those who went straight through an engineering college. As at present, colleges will have to exercise suitable selectivity in passing students from one year to the next, and this will be particularly so at the end of the first four years, since students can be graduated at that level with a "marketable" bachelor's degree which may well qualify them for certain varieties of industrial employment. On the other hand, we expect that before long only the full five years will constitute a fully recognized engineering curriculum suitable for commencing a professional career.

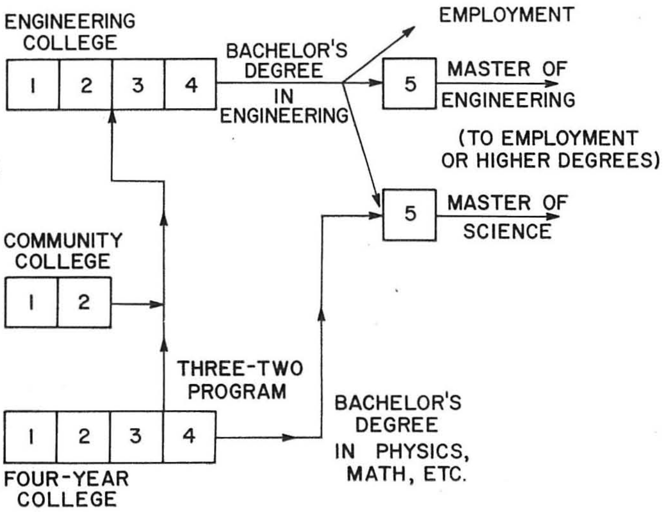



Figure D-18. Routes to master's degrees.

Another possible route, one which may become more important in the future, is indicated in the lower part of the flow chart. It serves a small but significant group of students who have obtained the bachelor's degree in other fields, such as physics or mathematics, either from universities or from the smaller liberal arts colleges.* Such students are turning to applied science as a preferred professional objective, and frequently have quite well-defined goals and technical interests. Most engineering colleges do and should take such students, requiring them to make up some but not all aspects of an undergraduate engineering program. Their broader preparation in basic science compensates to an adequate extent for the less complete coverage of engineering courses, particularly considering the likelihood that these graduates will work in functions closer to research than to broad engineering practice.

In Section 2 it was shown that many master's-degree holders are performing as professionals in a variety of functions (other than research or teaching, for instance), and it is clear from Section 1 that an increasing fraction of engineering students will and should combine the bachelor's and master's degrees in their preparation for an engineering career. To the extent that such combined programs are planned by the educational institutions, and to the extent that they possess a common core of generally accepted subjects agreed to by the profession, *it would be appropriate for the terminal degree to be designated the Master of Engineering.* Such a consensus could function appropriately whether the student completed both degrees at the same institution or at different ones (see the end of this section for current data on the extent of transfers). As an example, present practice in the field of sanitary engineering calls for a master's degree that may be taken at either the same or a different school from the bachelor's degree.

On the other hand, the Master of Science can continue to be used as a degree designation for engineering programs, especially when the graduate program is separate from the undergraduate one. This degree is within the concern, if not the actual jurisdiction, of the local graduate dean and faculty (or college or committee) and also of national organizations such as the Council of Graduate Schools in the United States. The latter group has, in fact, prepared a recent statement (Ref. D-18) which clearly indicates that an applied science such as engineering is properly included as a field for the Master of Science, and that in lieu of a thesis constituting a contribution to knowledge it is appropriate to require "a report or a synthesis or a design in the student's field."

For other students the master's program may occupy a different role, either in terms of their backgrounds or objectives. The objectives may be primarily the mastery of new and advanced levels of knowledge, as well as the techniques of inquiry, as preparation for research, teaching or further study. There need be no consensus of the profession as to which subjects should be in-

* Many more such students are potentially available; for example, substantial numbers of physics graduates are actually functioning as engineers. Many of these graduates, who have stopped at the bachelor's level, could continue to a master's degree in engineering.

cluded, nor is it necessary that the students' previous degree be in engineering—it could be in physics or mathematics, for instance. Such flexibility is better accommodated in a degree program designated Master of Science instead of Master of Engineering.

Thus, for some students the master's program is part of the basic professional program, commencing at the freshman level and extending over five years. For other students the master's program will be a self-contained graduate program. For still others it will be a terminal program, and for some it will be a stepping stone to the doctorate. Such distinctions present real dichotomies in certain disciplines, such as chemistry or history, for example, where the master's degree is clearly a stepping stone and accordingly suffers from the stigma of a "consolation prize" for unsuccessful doctoral candidates. Engineering is more fortunate in that degree holders at all levels are needed for the great diversity of engineering work to be done in industry and government. Difficulty seems to arise when a profession has a clearly accepted minimum of academic preparation; then any degree *short* of that level has an ambiguous role. Anything *above* the minimum level is welcomed. Thus, for the chemist or the historian the doctorate is the minimum level for full professional acceptability. For engineering the bachelor's degree will have the precarious role in the future, and the debate will be concerned with its dual role as terminal vs. preparatory. The master's degree will still be safe.

The unifying criterion of master's programs, no matter what their purpose, is the matter of advanced level. *The degree should never be awarded merely for a fifth year of undergraduate courses.* At the same time, too much should not be presumed for the master's degree. It cannot be considered a "research degree," in the sense of providing both adequate advanced course preparation and adequate apprenticeship in research experience. The best that can be expected is preparation in the advanced "tools," either for later research or for practice.

### *Teaching Methods*

Regardless of the academic route, the central characteristic of engineering is the creative synthesis of new systems and components. New learning experiences in this direction are much needed and should provide a real challenge to engineering educators. It became clear from the Institutional Reports (in 1964) that there is a scarcity of experimental programs at the master's level, even though nationally there has been much discussion. Group design projects, use of the case method, and other possibilities have been considered and are being tried in a few places, but more experimentation is needed.

In connection with planning the course content of master's degree programs, a caution is needed against the educator's compulsion to cover excessive blocks of subject matter, responding to pressures such as: "Every engineer must have a course in this, and this, and this." Obviously, some degree of comprehensive subject coverage is necessary, but attempts to achieve such in a four-year bachelor's program have presented virtually impossible conditions. Extension of basic engineering education to a five-year master's program will hopefully relieve this pressure and permit the faculties to combine subject coverage with more diversified pedagogy.

When subject coverage is the principal goal, it seems to be most efficient to lecture, to assign a single textbook, to assign problems from the book for drill, and to give exams based on the lectures and the book. The unfortunate consequence is that the student comes to depend on this kind of learning mechanism and in later years feels he must have formal continuing education in the same pattern. He should have had the opportunity—and the master's program may provide the first real opportunity—for experience under faculty supervision in critical and comparative reading of new engineering literature, both books and journal papers. He will acquire skill in efficient use of the library and of other resources. Less subject matter will be covered in a given time but he will "learn to learn." Thus, there is both need and opportunity for a limited amount of learning experience other than that obtained in formal courses, and this can be given different emphasis for different students.

This emphasis could indeed be oriented toward creative design experience, but the reports from the Institutional Committees in 1964 revealed very few existing programs having a design emphasis. At the same time, the majority of the respondents felt that "design is the heart of engineering," and that its importance will increase in the future (Ref. D-7, p. 218). Thus, the creative teaching of design offers opportunities for experimentation and improved pedagogy. One of the difficulties, as will be mentioned in Sect. 7 on Faculty, is that the qualifications of the usual full-time faculty member are not of a kind to provide realistic design experience. New kinds of faculty are probably needed, perhaps drawing more on active professional practitioners as is done in programs in medicine or architecture.

*It is recommended that more institutions undertake experimental master's programs exphasizing design, new pedagogy, etc., because too few of these now exist, compared to the extent of expressed interest.*

Master's degree programs are normally composed of lecture classes plus seminars and independent study work. Most of the course work should be at a level beyond the normal bachelor's degree, and no credit should be given for make-up courses, or for broadening in undergraduate engineering courses outside the major field.

Each student is entitled to have as an advisor a member of the engineering faculty.

It is most desirable that the degree be earned by full-time study, in preference to part-time study that extends over a protracted period of several years (see Section 10). One way of meeting this problem is to place a time limit, such as four years, after which courses taken will no longer be counted toward the degree (see Ref. D-18).

### *Thesis*

A master's thesis offers an opportunity for the student to engage in a creative, self-learning experience. When there is no doctoral program at a school, the master's thesis performs a vital role in providing this opportunity not only for the student but also for the teacher. If a school has a large doctoral program, then both the student and the faculty are better served if supervised research experience is emphasized at the doctor's level rather than the master's level. Such schools usually have large graduate course offerings, so that the master's students are able to take a full program of appropriate courses.

Two disadvantages must be noted in the master's thesis. Unless the faculty time spent in supervision is adequate, the student work may be neither good research nor good engineering (i.e., synthesis or design). If the supervision is intense, it is a great consumer of faculty time. It is essentially individual instruction, and hence is very costly. It seems clear that, if the national supply of master's graduates is to reach the levels recommended, there will not be the faculty resources available to permit the universal requirement of a master's thesis. Moreover, these scarce faculty resources must increasingly be conserved for supervision at the doctor's level, since the numbers there are increasing more rapidly.

The requirement of a master's thesis is no longer very common. The reports of the Institutional Study Committees showed that of the "large" and "medium-sized" schools, which together award two-thirds of all engineering master's degrees, only 25% have a thesis requirement in all master's programs. Of the smaller schools, which grant the remaining one-third of the degrees, 61% require the thesis. Finally, of those very small institutions which grant ten or fewer master's degrees per year, 90% require a thesis. These figures seem consistent with the observations made in the paragraphs above.

*Transfers Between Schools*

Students planning to undertake graduate study must decide whether to continue at the same school where they now are located or to transfer to another school. For example, some students transfer at the end of four years and go on for master's degrees elsewhere, while there are others who have studied continuously at the same school from the freshman year all the way to the doctorate.

The principal advantages of transferring from one school to another are (1) the opportunity to study with different faculty having new and different points of view, and (2) the possibility of upgrading, in the sense of going to a school that has better faculty and a more highly-selected student body. Both of these reasons are valid and can serve as guidelines for students facing a decision. Balanced against the opportunities mentioned in (1) and (2) may be better coordination of bachelor's and master's programs at the same school, plus practical considerations related to financial need, geographic preferences, family ties, etc. In addition, some undergraduates may wish to stay at their present school for graduate study because they believe that, in their particular field, their present school has the best graduate program. If such is the case, a student should feel no hesitation about staying at the same school.

The actual extent of transfers at the graduate level has not previously been reported, and therefore it seemed worthwhile to document what has been happening. It is especially important to do so in view of the increasing emphasis on graduate work as preparation for an engineering career. Furthermore, when the Goals Committee first recommended that five years of formal education be encouraged as a minimum, concern was expressed that adoption of this recommendation would cause too many students to stay at the same school for both bachelor's and master's degrees.

This matter has been carefully examined. Through the Industry-Government Survey, data are available showing that, of those who have master's degrees in engineering, the percent who received both bachelor's and master's degrees at the same school has been rising slowly and steadily for a long time (Fig. D-19), and is 50% or more at the present time. There is very little difference between the major branches of engineering in this respect (see Fig. D-20), and there is no evidence that any one field, such as civil or chemical engineering, has successfully established a uniform tradition of encouraging its students to change schools after the bachelor's degree.

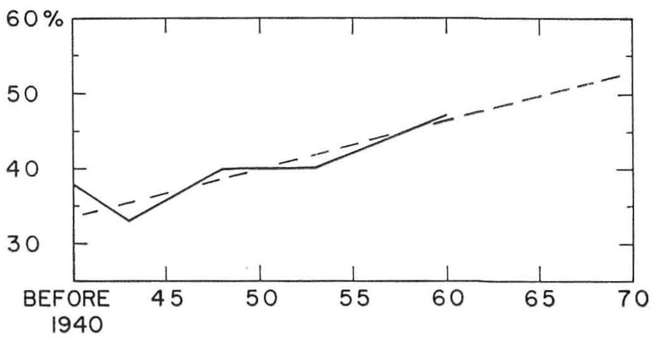



Figure D-19. Bachelor's and master's degrees at same school by year of bachelor's degree.

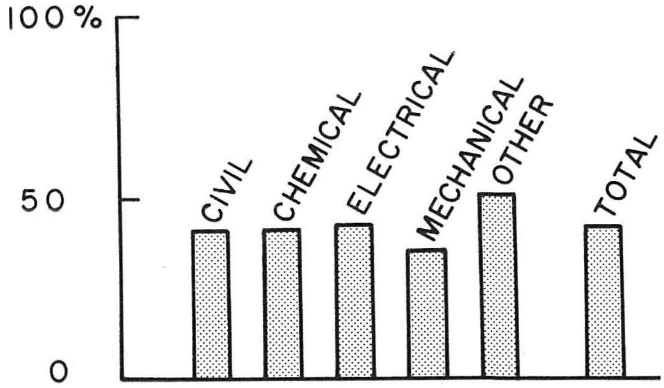



Figure D-20. Bachelor's and master's degrees at same school by fields of engineering.

# 5. THE DOCTOR'S DEGREE

### *Role of the Doctoral Engineers*

A quarter of a century ago, only 100 doctor's degrees were granted annually in engineering. Yet among those graduates were men who have since become leaders in the profession: important technical innovators, presidents of corporations, of universities, and of the major engineering societies. These men sought the highest level of education available to them, and then went on to attain important and productive roles in our technical society.

The trail thus blazed is now being followed by ever increasing numbers of talented and ambitious students. About 2,300 received the doctorate in engineering in 1966, and if the trend continues the annual graduation rate could reach 8,000 by the end of another decade (1978), as shown earlier in Fig. D-3. It should be noted for perspective that although this number will be large, it represents only 16% of the estimated number of bachelor's degrees for that same year, so we are discussing only a small, select group. Nevertheless, the number will grow, and although various deficiencies of the doctorate may be debated, the fact of this rising tide of doctoral aspirants is inescapable.

Periodic surveys by the National Education Association indicate that 30% or more of the engineering doctorates who take new jobs following receipt of the degree go into teaching positions (Ref. D-19). To this should be added a few more who are already in teaching positions while working on their doctorates. Analysis of data obtained in a University of California alumni survey (Ref. D-20) indicates that at least 26% of their doctorates are now in teaching. The Goals survey of the graduate engineering schools shows a growing preference for doctoral graduates for new faculty positions. Whereas 59% of the 1964 engineering faculties held doctor's degrees, the percent of *new* appointees with doctorates has climbed steadily to a level of 86% in 1964. This trend is discussed further in Section 7 on Faculty.

The Industry-Government Survey clearly shows, as illustrated previously in Figs. C-1 and D-12, that doctoral engineers tend to concentrate in those functions where both high technical qualifications and creative talents are needed, e.g., research or development. Further, some 16% are in management, which demands and rewards creative leadership, even though it is less technical than research or development. Doctoral engineers tend to be even more highly concentrated in research and development at the time of their first jobs after graduation (see Figs. D-12 and D-13). However, the figures also show that doctoral engineers tend to shift slightly from technical functions to management functions with the passing of time. Other differences between the degree levels are documented in Section 2 and in Ref. D-8 (see Figs. 11, 12, 17, and 22 to 28 of that reference).

It should be made quite clear that a doctoral program must definitely not be regarded solely as preparation for a research career, even though it may be the best preparation for such a career. *Instead, doctoral study should be regarded more broadly by educators and employers alike as preparation for the highest levels of creative leadership throughout the profession, first, because of the high degree of selectivity of the students as to intellectual aptitude; secondly, because of their proven motivation and achievement; and lastly, because of the benefits of the doctoral program itself.*

### *The Engineering Doctorate in the University*

Much has been written in the past concerning the major considerations in university doctoral programs, and anyone concerned with such programs should read several of these discussions (for example, Refs. D-21 to D-25). Rather than repeat all of these considerations in this report, however, it is more appropriate to comment on some current issues and problems of engineering doctoral programs and their operation in the contemporary university.

Most doctoral programs in engineering have led to the Doctor of Philosophy degree, whereas only a few lead to the Doctor of Engineering or Doctor of Science degrees. This pattern is largely a matter of tradition, but there have been certain advantages for engineering. The Ph.D. degree has the highest prestige in the academic world, a prestige which has been carefully guarded by academics for more than a century. Other doctoral degrees have been introduced in professional fields, but these have usually suffered by comparison with the Ph.D. If the requirements for a doctoral degree are different from those for the Ph.D., they are likely to be viewed as lesser in quality rather than as merely serving a different purpose. Even the well-established Doctor of Medicine degree is sometimes regarded in the universities as inferior to the Ph.D. However, the medical profession can ignore any such meaningless comparisons made by persons outside their profession because the M.D. serves an important purpose to them, namely preparation for professional practice. Engineering, in contrast, has no established tradition of formal professional education of such duration and depth as to be appropriate for a doctor's degree. However, engineering students increasingly are seeking higher levels of education in preparation for diverse professional practice, and hence it will become more feasible to consider alternatives to the conventional Ph.D.

The benefits of the Doctor of Engineering degree programs could be both practical and symbolic. On the practical side there is the matter of program content and jurisdiction thereof. Control over the Ph.D. is generally held by some form of graduate council of the university, and although engineering faculty are represented on such a council they usually constitute a minority. In actual practice, as evidenced by a Goals Study survey of all graduate engineering departments, relations with such graduate councils have been reported more often as satisfactory than otherwise. Nevertheless, there is a potential hindrance to experimentation with varied engineering doctoral programs.

Though the addition of Doctor of Engineering programs and degrees may be desirable, even a small shift away from the Ph.D. is bound to be a slow process. There are no strong forces to propel change, either to reject the Ph.D. or to demand the Doctor of Engineering. The Ph.D. is serving well in many universities. On the other hand, strong institutions can always experiment. For instance, the University of California at Berkeley has been offering both degrees for several years, and while only about 10% of the students have been electing the Doctor of Engineering degree, a small but steady flow of graduates could eventually establish a trend.*

The title Doctor of Engineering is an attractive one, and might be preferred by engineers and employers who deal with a public less concerned with academic traditions. Paradoxically, the prestige of the Ph.D. is great because of the pure academic disciplines, whose members have little respect for the presence in the academic community of applied disciplines such as engineering. Engineering might well, by relinquishing its borrowed prestige, gain more than it would lose, and be more free to incorporate greater professional relevance in program content.

One obstacle to adoption of the Doctor of Engineering is its present use at several institutions as an honorary degree. This can be changed, however, as happened with the Ph.D.; the last honorary Ph.D. was awarded in 1939.

### *Doctoral Research*

A critical aspect of the doctoral requirements has to do with the nature of the research which provides the dissertation. Must it be scientific research or can it comprise more of the elements of engineering, such as synthesis or design? Turning to the statement on "The Doctor of Philosophy Degree" (Ref. D-24), one finds the phrase, ". . . research which is a significant contribution to knowledge. . . ." The only reasonable interpretation of the phrase is that it implies that the contribution must be relevant to the body of knowledge in the field in which the degree is granted. It is obvious that a contribution to chemical knowledge is not relevant to a degree in sociology; neither should a contribution to the laws of physics be expected for a degree in engineering. The body of knowledge of engineering clearly overlaps the fields of physical science, such as physics and chemistry, but it also includes knowledge of the behavior of man-made systems and components, as well as techniques for synthesizing such systems and components. Research dealing with any of these aspects should be appropriate for the doctoral research, and it seems to be the experience of most engineering schools that these various aspects can be adequately emphasized.

The contribution to knowledge must be unique, and thus the research provides an important creative experience for the student. Indeed, the successful completion of this creative experience makes the doctoral program a valuable career preparation; the creativity thus encouraged can be turned to any aspect of the engineering profession, as well as research itself.

Thus, it would be possible for engineering education to continue utilizing the Ph.D. while emphasizing "design" or something else. It must be recognized, of course, that the doctorate represents a high level of academic attainment, for the engineer in particular a high capability in subjects such as mathematics, physics, or chemistry. Hence any dissertation which emphasizes creation of new design techniques can reasonably be expected to draw upon this advanced learning. The unique contribution to knowledge must be of such a level that it could not equally well have been achieved by someone with only a bachelor's or master's level of education.

One can, of course, challenge the relevance to engineering practice of a creative experience which requires only a contribution to *knowledge,* whereas engineering is more concerned with providing society with the goods and services it needs and wants. Here we must acknowledge the limitations of the university environment in duplicating the "outside world." But one must not ask the university to attempt that which it cannot do well. It is better for the student to have a high quality creative experience of a variety suitable to the university world, than an inferior one which attempts to simulate the world of engineering practice. Knowledge constitutes the natural commodity of the university world—both as to its dissemination and extension—and as such provides the best medium in which students and faculty may cooperate in creative endeavor.

In addition to the great value of the creative experience provided by the dissertation requirement, two other requirements are comparably important, at least under the limitation of our present customs of higher education. One of these is the experience of the qualifying examinations. These usually are comprehensive exams, covering for the first time in the typical student's academic career the whole span of subject matter which he has taken piecemeal in separate courses, without ever having had to integrate this knowledge in an adequate manner to permit answering wide-ranging and searching questions. The exams, moreover, are frequently oral, a new experience of "thinking on his feet." Those who possess this kind of ability, by aptitude or preparation, are of particular value in the engineering profession. Finally, the doctoral program provides the student with his first significant experience in independent learning, where he is responsible for mastering a new domain of knowledge without the assistance of a complete course of organized lectures, together with a seasoned textbook chosen for him by the instructor. Thus, the successful doctoral candidate should be off to a good start on a career in a profession which will require him to keep up with an ever changing body of knowledge.

*It is recommended that doctoral programs in engineering be improved and broadened, and that educators expand the opportunities for the increasing numbers of engineering students who will seek the doctor's degree.*

* A recent report of the University of California Engineering Advisory Council advocates the Doctor of Engineering degree as the primary doctor's degree in engineering (Ref. D-26).

*Transfers Between Schools*

Doctoral graduates in engineering usually study at more than one school during their academic careers. This was brought out in the Goals survey of 1963 doctoral graduates, which showed that only 23% of the graduates received their bachelor's, master's, and doctor's degrees from the same school. The remaining 77% changed schools either at the bachelor's or master's level. Comparable results were obtained from the data of the Industry-Government Survey.

# 6. INTERMEDIATE GRADUATE DEGREES

There is a category of degrees that is intermediate between the master's and doctor's levels. Such degrees usually carry the designation, "Engineer," "Civil Engineer," etc.* Comparatively few schools offer this level of degree, although the number of degrees awarded has increased somewhat (see Fig. D-3). The institutions awarding intermediate graduate degrees during the last four years are shown in Table D-4. Some schools have offered the engineer degree for many years (e.g., Stanford since 1894); others have instituted it during the past twenty years (e.g., Cal Tech and M.I.T.). The number of schools awarding the degree each year since 1950 has fluctuated from seven to twenty-three.

TABLE D-4

INTERMEDIATE GRADUATE DEGREES

| Institution | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|
| University of Arizona | 4 | | | |
| California Inst. of Tech. | 13 | 7 | 8 | 8 |
| Columbia University | 21 | 34 | 24 | 36 |
| University of Idaho | | 1 | | |
| Massachusetts Inst. of Tech. | 83 | 98 | 97 | 126 |
| University of Michigan | 6 | 11 | 13 | 10 |
| University of Minnesota | | 2 | 1 | 1 |
| North Carolina State U. | 9 | 8 | 12 | |
| University of Oklahoma | 1 | | | |
| Oregon State U. | 2 | 3 | | |
| Stanford University | 31 | 36 | 35 | 41 |
| U. S. Naval Postgraduate School | 1 | | | 6 |
| U. of Southern California | 3 | 2 | | |
| Swarthmore College | | 1 | | |
| Texas A & M University | 1 | 1 | | |
| U. of Wisconsin | | | | 1 |
| Total | 175 | 204 | 190 | 229 |

The degree typically involves two years of graduate work beyond the bachelor's degree, and usually involves a thesis. In some cases the program lies along the same path as the master's and doctor's programs, whereas in other cases there is a truly separate path to the engineer degree which does not lead on to the doctorate. The latter case is an interesting one, offering possibilities which the engineering schools might well re-examine in the decade ahead, when the master's degree will tend to become the normal first professional degree. *An intermediate graduate degree provides the opportunity for an advanced program to meet special professional objectives,* such as advanced design competence in a particular field of engineering. Experimentation with such programs will be far easier than with the Ph.D., since the requirements for the engineer degree can usually be determined by the engineering faculty alone, without involving all the segments of the university which are concerned with the Ph.D. The opportunity for experimentation at the intermediate level is especially good in those schools which do not now have such a degree, since it seems to be characteristic of our educational enterprise that it is easier to add something than to change something.

The designation of the intermediate degree need not be the present one. It is not widely used, and could be superseded by something like "Master of Engineering" (corresponding to the two-year Master of Business Administration) if a sufficient number of institutions adopted it; otherwise, a two-year master's degree would not compete well with a one-year degree, just as the five-year bachelor's degree is losing out against the four-year degree.

The role of the engineer degree as a stepping stone along the path from the master's to the doctor's degree risks the inevitable stigma of the "consolation prize" (for the unsuccessful doctoral candidate). Of course, this stigma necessarily attaches to whatever degree is next below the doctorate, including the master's degree if it occupies that position.** There is a difference, however, if the *only* recipients of the "next best" degree are the unsuccessful students. If a school awards a great many master's degrees to students for whom that degree is their terminal objective, then the presence of a few unsuccessful doctoral aspirants is quite inconspicuous. As long as the engineer degree represents a significant accomplishment beyond the master's degree, it can be judged upon its own merits. This consideration argues for intermediate degree programs which have well-defined objectives lying along a path quite different from the route to the Ph.D.

Nevertheless, one or more schools seem to operate quite successfully with a "stepping stone" role for the engineer degree. The admission of students to the intermediate degree is more selective than for the master's degree, although less so than for the Ph.D. The requirements to complete the degree are also intermediate, and serve the needs of students who cannot afford the longer doctoral program. *The existence of a long tradition and an adequate number of graduates each year gives the degree an established role.*

*It is recommended that engineering schools utilize more fully the opportunities provided by intermediate graduate degrees (degrees between the master's and doctor's level) for experimentation with new educational programs.*

* In the past there was a different class of degrees carrying this kind of title, awarded to practicing engineers having five or so years of experience and submitting a thesis based upon their work. No formal graduate study was involved. This nonresident degree has essentially disappeared, upon recommendations of both the profession and the academic community.

** This is a matter of concern in chemistry, where the master's degree is simply a step on the way to the Ph.D. (see p. 83 of Ref. D-27).

# 7. FACULTY

*The quality and competence of the faculty are probably the most important factors in the success of any engineering program.* As stated in the Grinter report, "Distinguished faculties are far more important to the advancement of engineering education than details of curricula or magnificence of facilities" (Ref. D-28, p. 6). The importance of faculty quality also was brought out clearly in the study of some sample schools;* at all four of the sample schools this factor was considered to be the most important ingredient of their successful development and growth.

### Educational Background

The kind of faculty competence required is not the same for all types of advanced engineering education, although the degree of competence should probably always be at the same high level. Emphasis in recent years in the selection and advancement of professors has generally placed a high value upon research experience and publications. Possession of a doctoral degree, representing an advanced level of educational attainment and creative endeavor, has been increasingly favored as a prerequisite for teaching. This trend is shown clearly in the data portrayed in Fig. D-21. The figure shows the percent of new engineering faculty hired with doctor's degrees (as compared to those without doctor's degrees); this percent has grown in a steady trend from 32% in 1940 to 86% in 1964. It should be kept in mind that only schools giving graduate degrees in engineering were included in the survey from which this figure was compiled; also, only full-time, regular faculty were included.** (A similar trend is shown in data collected by the Ford Foundation: see Table C-2, Part C.)

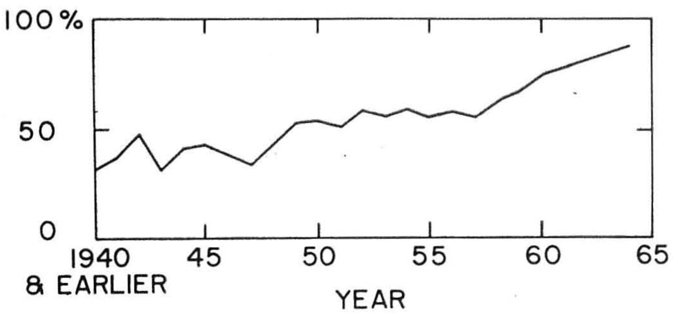



Figure D-21. Percent of present faculty hired year-by-year with doctorates.

The survey also showed that an overall total of 59% of engineering faculty members possess the doctorate (see Fig. D-22). In addition, it was found that the large schools have a higher percentage of doctorates (70%) than do the small schools (53%), and that the percentage is slightly higher for full professors than for assistant professors. By comparison, the percent of physics faculty having a doctor's degree is 90% in those institutions granting Ph.D.'s in physics, and 63% in institutions granting master's degrees in physics (see Ref. D-29, p. 23).

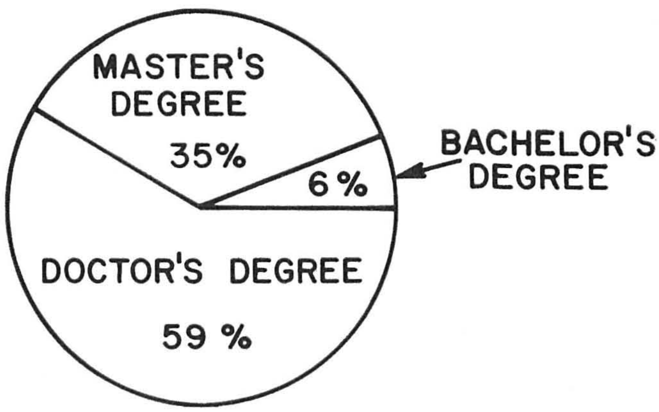



Figure D-22. Highest degrees held by professors in engineering.

In addition to recognizing that a larger percentage of new faculty being hired have the doctor's degree, we must also recognize a growing need for more faculty, since the number of students seeking doctoral education is growing (see Figs. D-2 and D-3), as is also the number of institutions giving doctors degrees (see Fig. D-8). All of these effects mean that more doctoral graduates will be needed to teach in our colleges and universities. *Thus, the training of college teachers will continue to be an important role of graduate education.*

In Section 5 the case was presented for the doctor's degree as appropriate education for the highest levels of professional work in engineering. This appropriateness is even more relevant to engineering teaching, especially for faculty in advanced-degree programs. Successful participation as a student in a graduate program to the highest level is an experience which is directly applicable when the student becomes the professor. Successful experience in independent learning is also a good beginning step for a career which demands this each year. The passing of comprehensive oral exams is likewise good preparation for the dialogue of the classroom, as well as providing time for an overall review of the student's prior work.

From the standpoint of the national needs it is vital that an adequate share of the new doctoral graduates each year goes into teaching. With the competition from industry and government constantly growing, this problem becomes of more interest. There have been several attempts to measure the percent of doctoral graduates that go into teaching each year. From a report of the NEA it appears that about one-third of the doctoral graduates in engineering go into college teaching (see Ref. D-19). A survey of graduates of UCLA (Ref. D-20) showed that about 26% of their doctoral graduates entered teaching. These figures are reasonably consistent and suggest that in the near future we can expect about a third of the engineering doctoral graduates to be available for filling teaching positions. This will probably not be sufficient to staff fully the college and university expansion.

The importance of adequate training of college pro-

* This study consisted of a detailed investigation of four schools selected as being typical of high-quality graduate engineering schools; further description is given in Section 11.

** Most of the data given in Sections 7, 8, and 9 of this report were compiled from the Institutional Reports sent to the Goals Staff in response to Information Document No. 4.

fessors must be kept foremost in our minds. Each professor must have a command of his field and should be capable of engaging in creative research. He should, of course, be given adequate time to study and keep abreast of his field, as well as to counsel and supervise students.

Another factor that must be considered with respect to faculty qualifications is the need for experimentation with new graduate programs, especially at the level of the master's or the engineer degrees. In particular, *we may need to draw more upon practicing engineers to provide a current atmosphere of design orientation.* In such cases the degrees held will be less relevant than the nature of the instructor's past experience and present involvement.

*It is recommended that engineering schools offering advanced degrees continue to require a high level of competence on the part of new faculty, usually including education to the doctoral level.*

*Designation of Graduate Faculty*

Some universities follow a practice of distinguishing between graduate faculty and undergraduate faculty, and therefore the Goals study asked the engineering schools to explain their practices in this regard. At most schools it appears that the distinction has little practical significance because almost all of the faculty have been designated as graduate faculty. Also, at most schools the professors are involved with both undergraduate and graduate students, although in some cases there is a substantial number of professors who teach only undergraduate courses. Of the four sample graduate schools (see Sect. 11) only one has a formal designation of graduate faculty. In general the designation of graduate faculty appears to be of concern only in a local sense, and its efficacy depends upon the administrative arrangements.

*Sources of Faculty*

The major sources of engineering professors, especially those who hold doctorates, were examined by the Goals study. The principal sources are shown in Table D-5; the twelve schools listed in the table have shared in providing over one-half of the faculty doctorates. Note that over 4,500 professors are included in the survey, which comprised the full engineering faculties (as of 1963) from more than 80% of the engineering schools having graduate work. It is not surprising that the list contains the largest graduate engineering schools, which are the primary doctoral producers.

TABLE D-5
INSTITUTIONAL SOURCES OF FACULTY DOCTORATES
(AS OF 1963)

| No. | Source Institution | No. of Doctorates |
|---|---|---|
| 1 | Massachusetts Inst. of Tech. | 436 |
| 2 | University of Illinois | 262 |
| 3 | University of Michigan | 246 |
| 4 | Purdue University | 212 |
| 5 | Stanford University | 190 |
| 6 | Iowa State University | 164 |
| 7 | University of Wisconsin | 161 |
| 8 | California Inst. of Tech. | 143 |
| 9 | Columbia University | 133 |
| 10 | University of California (Berk.) | 127 |
| 11 | University of Minnesota | 122 |
| 12 | Ohio State University | 121 |
| | Subtotal | 2317 |
| | All Other Institutions | 2204 |
| | Total | 4521 |

A perennial subject of discussion relevant to faculty in any field is the matter of "inbreeding," that is, the hiring of the school's own graduates for faculty positions. One measure is the number of professors having all of their degrees from the same school where they are teaching. The Institutional Reports showed that 20% of the engineering professors are in this category, with the percent being higher for the larger schools (24%) than for the small schools (17%). Also, the percentage is higher for assistant professors (23%) than for full professors (17%).

A similar measure is the number of professors having their doctor's degrees from the same school where they are now teaching. This percentage is much higher for the large schools (47%) than for the small schools (17%), presumably because the large schools are the major producers of doctor's degrees. The overall average is 29%.

Whether this situation is desirable or not probably depends primarily upon the individual professor and his school. Certainly the broader experience gained by changing schools is desirable, but on the other hand a large, high-quality school may be able to offer one of its own graduates more variety and a more challenging situation than could be found at a small school that was not well established. It seems clear that "inbreeding" has been no deterrent to success, because the most highly regarded schools are the larger ones, and these schools consistently have the highest percentages of faculty with doctoral degrees from their own school.

*Continuing Engineering Studies for Faculty*

*Continuing studies are as important for engineering faculty as for engineers in industry and elsewhere.* There is certainly a general concern among engineering faculty about this problem, as was brought out in the Institutional Reports. A majority (71%) of the reports indicated that faculty obsolescence is a definite problem, and 16% even indicated it was a severe problem (see Fig. C-3). The purpose of continuing studies is very much the same for teachers as for others, that is, updating the person's degree and diversifying to new fields that have become important. Most of the Institutional Study Committees reported that summer programs were very helpful in this regard, but that more such opportunities were needed and more financial assistance to the professor was necessary. Existing opportunities for continuing study at a professor's own institution are generally of an informal nature; for example, classes and seminars can be attended. Research, sabbatical leaves, and consulting also serve a role in continuing education. It appears, however, that many schools must give more serious attention to continuing studies for the faculty. (See also Part C, Sect. 4).

*It is recommended that engineering schools provide adequate opportunities for upgrading, updating, diversifying, and broadening the capabilities of individual professors.*

# 8. STUDENTS

Quality of students, as well as quality of faculty, is a major factor in advanced engineering education. Careful selection among student applicants is vital, of course; at the same time it must also be acknowledged that some qualified students may actually need encouragement to continue their education instead of accepting immediate employment.

### *Admission of Students*

Admission practices and policies determine the degree of selectivity of students at a particular institution, and hence the standards of advanced study that can be maintained. Not all schools can or will be equally selective. One way of evaluating an institution's ability to be selective is to examine information on applications, admissions, and actual arrivals. Such information was compiled by the Goals study for Autumn 1963, and a summary of results is shown in Table D-6. In the table there are separate data for students applying from other institutions and for students applying from their own institutions. The latter tend to know the local admission standards; hence, fewer apply who do not meet these standards, and the percent of admissions is higher (82% versus 58%). Since they also know the local advantages, the percent of arrivals is higher (76% versus 54%). The number of applicants from "other schools" should be an indicator of the attractiveness of a school's graduate program.

TABLE D-6
ADMISSIONS OF GRADUATE STUDENTS

| | From other institutions | From own institution |
|---|---|---|
| Applications (percent of total applications) | 86% | 14% |
| Admissions (percent of applications) | 58% | 82% |
| Arrivals (percent of admissions) | 54% | 76% |

A measure of the degree of selectivity on the part of a school can be found in the percent of applicants from "other schools" who were admitted. While the average in this category was 58% (see Table D-6), among the individual schools it ranged from a low of 13%, representing very high selectivity with only one out of eight applicants being admitted, to a high of 95%, representing almost no selection at all on the part of the school. In the latter case the students are selecting the school, rather than the school selecting the students.

The percent of arrivals from other schools (as in Table D-6) is some measure of the attractiveness of a program compared to that of other schools to which a student has been admitted. The relative percentages for individual schools provide a useful comparison, whereas the absolute level for all schools together is somewhat of a measure of the extent of multiple applications on the part of prospective students and will vary from year to year.

Admission standards to graduate study may vary over the years, and are of special interest during periods of rising enrollments when there is apt to be a concern that increasing numbers of students might mean lower standards. The Goals study inquired about admission criteria for the master's degree, and asked the Institutional Study Committees whether standards have been changing and in what way. *The majority of the schools responded that "standards have increased," or that they were "higher" or "tighter."* The remainder stated that there had been no particular change in admission standards. Inasmuch as we have been in a period of great growth in engineering enrollments and degrees (see Section 1), these statements by the faculty assume added significance. *They show not only that it is possible to expand without lowering standards, but that standards can actually be raised.* (During the discussions of the Preliminary Report there was brought out many times a genuine concern about lowering of standards if the Goals projections of number of degrees should be realized. Since no evidence of a lowering was reported by the schools, even when we specifically inquired about it, it seems safe to say that this worry is unfounded).

### *Foreign Students*

The number of foreign students taking advanced study in engineering is growing each year, and has already reached a substantial level at some institutions. In providing an education for students from other countries, schools are contributing to international progress and cooperation. Foreign students on a campus also produce a more cosmopolitan student body, with consequent advantages to the U.S. students. Furthermore, many foreign students contribute directly to engineering in this country, both as research students in college and later as employees of industry, government, or the educational institutions themselves.

The Goals study of the 1963 doctoral graduates in engineering shows that 80% received all of their degrees from U.S. universities, whereas 20% received the bachelor's degree from a foreign university. Similarly, graduate enrollment figures for autumn 1963 (see Table D-7) show that 17% were foreign students. These figures dispel any possible concern that the growth in doctoral output in the U.S. has taken place largely because of an influx of foreign students. Engineering doctoral degrees have been doubling every 5½ years (a rate of 12% per year) since 1900; such an increase is obviously not possible without the major growth occurring in the number of U.S. students.

TABLE D-7
ENGINEERING ENROLLMENTS AT THE GRADUATE LEVEL
(AUTUMN 1963)

| | U. S. Citizens | Foreign Students | Total |
|---|---|---|---|
| All students | 83% | 17% | 100% |
| Full-time students only | 75% | 25% | 100% |
| Part-time students only | 93% | 7% | 100% |

Engineering has a slightly higher percentage of foreign students receiving doctorates than do other fields. For the years 1960 and 1961 the figures for the other fields are as follows (see Ref. D-30, p. 30): physical sciences, 15%; biological sciences, 17%; social sciences, 10%; arts and professions, 8%; education, 5%; and total for all fields, 12%. This suggests that other countries have their greatest need for advanced education in the engineering fields.

In Table D-7 a distinction is made between "full-time" students (in the sense of "geographically full-time"; that is, either studying full-time on campus or partially employed on-campus as teaching or research assistants) and "part-time" students, who are employed off-campus in industry and elsewhere. The foreign students represent 25% of the full-time students, but only 7% of the part-time students. Thus, it is clear that foreign students are much more apt to be full-time than part-time.

### *Baccalaureate Origins*

The origins of the 1965 doctoral candidates in engineering were studied in detail (Ref. D-31) and it was found that about 93% of them had engineering baccalaureates. The other 7% came from physics, mathematics, chemistry, and other fields (in that order, numerically). This latter figure of 7% is small, especially in view of the fact that large numbers of people from other fields actually work as engineers. For example, many thousands of physics bachelor's graduates are employed in engineering functions. We may expect that such persons, in common with baccalaureate engineers, will have desires for advanced study in engineering. Thus, it behooves engineering educators to provide master's and doctor's programs that accommodate persons from other baccalaureate fields.

### *Time Lapse*

The time lapse between bachelor's and master's degrees, and between bachelor's and doctor's degrees, is of interest in the present era of large-scale fellowship programs which are designed to decrease the time lapse. The Goals survey of 1963 doctoral graduates in engineering showed that the average interval between bachelor's and doctor's degrees was 8.0 years, and between master's and doctor's degrees was 5.1 years. This elapsed time is, of course, greater than the average length of time spent in actual study toward a degree, since in some cases it includes time spent in military service, professional employment, etc. By comparison with the above figure of 8.0 years, another study showed that the 1960 and 1961 engineering doctorates averaged 8.3 years between bachelor's and doctor's degrees (Ref. D-30, page 40). These figures, which are for different years, are in excellent agreement. Physics and chemistry have a somewhat shorter time lapse than engineering for the 1960 and 1961 graduates (7.6 and 7.0 years, respectively), whereas mathematics is a little longer (8.5 years). By taking positive steps to insure that qualified doctoral candidates make steady progress, it should be possible to reduce the time lapse a little, and hence increase the efficiency of the educational system. As a result, the engineering profession will be provided with productive doctoral graduates at an earlier age.

### *Degrees From Same Institution*

The Goals study of the 1963 doctoral awardees shows that 23% obtained all degrees from the same institution and 63% received both the master's and doctor's degrees from the same institution. Apparently the majority change schools after the bachelor's degree and then do all of their graduate work at one institution. These figures include foreign students; if only U.S. citizens are considered, the percentages are higher.

### *Mobility*

At various times concern has been expressed about the limited mobility of graduate students and the resulting need for more widely distributed doctoral institutions. In order to investigate mobility of students, the 1963 doctoral graduates were studied in detail, and a compilation was made that showed how far these graduates traveled to reach their doctoral institutions. Only travel from one school to another within the U.S. was considered, and the distances were taken as straight-line mileages from city to city (actual travel distances are greater). For instance, the distance from Cambridge, Massachusetts, to Berkeley, California, was taken as 2700 miles in this compilation.

A summary of average miles traveled is shown in Table D-8. In the table a distinction is made between students who changed schools, that is, who traveled to their doctoral institution from some other school, and those who stayed at the same school (the doctoral institution itself) for the entire time that they were in college. Of those who changed schools, some went to their doctoral institution from their bachelor's degree institution and some went from their master's degree institution. These two cases are shown separately in the table, and it is seen that those who transferred after the master's degree generally traveled farther than the others. The average distance traveled by all students who transferred is 720 miles. The individual distances ranged from 0 to over 2,500 miles. About 30% of the students did not change their geographic location (that is, they stayed in the same city), and if they are considered in the calculations, the average distance traveled is 500 miles. Those who attended schools on the Pacific coast tended generally to travel greater distances than the others. There are only 1,038 doctoral awardees accounted for in the data because, as mentioned previously, those who came from foreign institu-

TABLE D-8
DISTANCES TRAVELED BY DOCTORAL GRADUATES FROM FORMER INSTITUTION TO DOCTORAL INSTITUTION

| | No. of Students | Average Miles Traveled |
|---|---|---|
| Students who changed geographic locations: | | |
| Bachelor's degree at former institution | 387 | 630 |
| Master's degree at former institution | 327 | 820 |
| Total | 714 | 720 |
| Students who stayed in same location | 324 | 0 |
| All students combined | 1038 | 500 |

tions were omitted. By comparison with the above figure of 500 miles, first-year graduate students having NSF Graduate Fellowships traveled an average distance of 740 miles from their undergraduate institution to their selected graduate institution, suggesting that when adequate financial support is available, students are quite mobile in their selection of an institution.

The distribution of the doctoral graduates with respect to miles traveled is shown in the chart of Fig. D-23. The ordinate represents the number of graduates, expressed as a percent of the total number of doctoral graduates, who traveled the indicated number of miles or farther from their former school to their doctoral school. In other words, 100% of the graduates traveled zero or greater miles; 50% of the graduates traveled 250 or more miles; 25% traveled 700 or more miles, etc. In general, it appears from this figure that engineering students are not hesitant to travel considerable distances when changing schools, and that the exact location of new doctoral institutions should not be a major consideration.

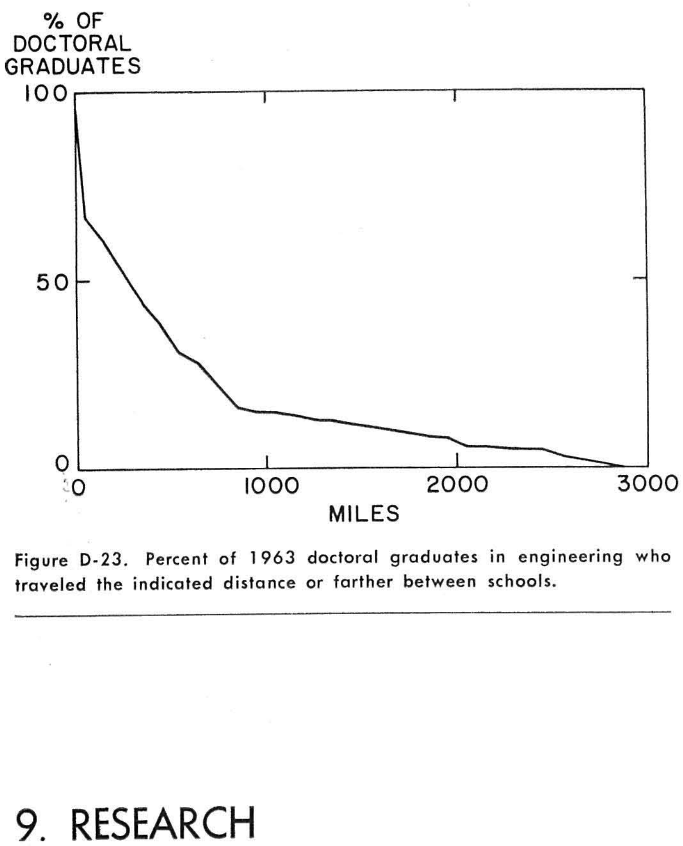



Figure D-23. Percent of 1963 doctoral graduates in engineering who traveled the indicated distance or farther between schools.

# 9. RESEARCH

### *The Research Function in Engineering Education*

Research has an important role in the universities as a creative experience for graduate students and as a continuing learning process for the faculty. Furthermore, it is generally accepted that the universities have an obligation not only to disseminate and store knowledge, but also to extend the frontiers of knowledge. *In engineering colleges it is vital that there be the fullest possible integration of research with the educational purposes of the institution.*

In their pursuit of research the universities should not be regarded as competitors with industrial firms which also conduct research. The purposes are different, even though the subjects, techniques and the resulting new knowledge may be similar. Engineering research in the university is preoccupied with creation of new and useful knowledge, usually made public immediately with little or no concern for building up a proprietary position with respect to such knowledge, and leaving it to other organizations to produce goods and services from the knowledge. An almost reverse set of priorities is typical in industry and the pursuit of research for solely military, industrial, or proprietary purposes is normal.

### *Research Support*

Engineering research of high quality can be costly, especially when extensive experimental work or computer time is involved. Fortunately, during the past two or more decades there has been a steady increase in financial support of university research, both from the federal government and from other sources. This support provides not only the direct costs of research but also other benefits to students and faculty (such as reduced teaching loads during the academic year, summer salary, travel to conferences, report reproduction, etc.). This recent era of support has resulted primarily from a new national view that scientific and technological research is in the federal interest, as has been the case with agricultural research for a century or more. Some dissatisfactions with the present system may exist, such as the high proportion of support from military agencies and some difficulties in getting support for young faculty. Nevertheless, support of faculty and student research in engineering colleges has climbed steadily, and it is important that this increase continue as the number of graduate students increases. Improved methods for allocating funds to institutions and individual professors are evolving.

A graph of research expenditures and the federal budget is shown in Fig. D-24. The first curve in the figure portrays the total federal budget, which has been increasing since the end of World War II at an annual rate of about 5%. Federal research and development ("R & D") expenditures have been increasing at a much higher rate, and have reached a point where they represent about 15% of the federal budget. The budgeted R & D expenditures for 1965 and 1966, however, show a marked leveling off from the previous rate of increase.

Basic research in the universities in all fields has been increasing at an annual rate of about 17%, while engineering research in the universities has been growing at about 12% per year. The latter growth rate is about the same as the growth in engineering master's and doctor's degrees (see Fig. D-3), which is not surprising in view of the close relationship between research and advanced degree education. A comparison of the curves for university engineering research and doctor's degrees is shown in Fig. D-25, and the similarities in the growth trends are clearly seen. Assuming that this growth continues, the level of research support to engineering graduate schools should increase from its 1963 level of

$160 million to $700 million or more by 1978. If this support should not continue, we would have to expect a decline in doctoral graduates, with consequent losses of talent for the engineering profession. The federal government is the largest sponsor of this research, as shown in Fig. D-26.

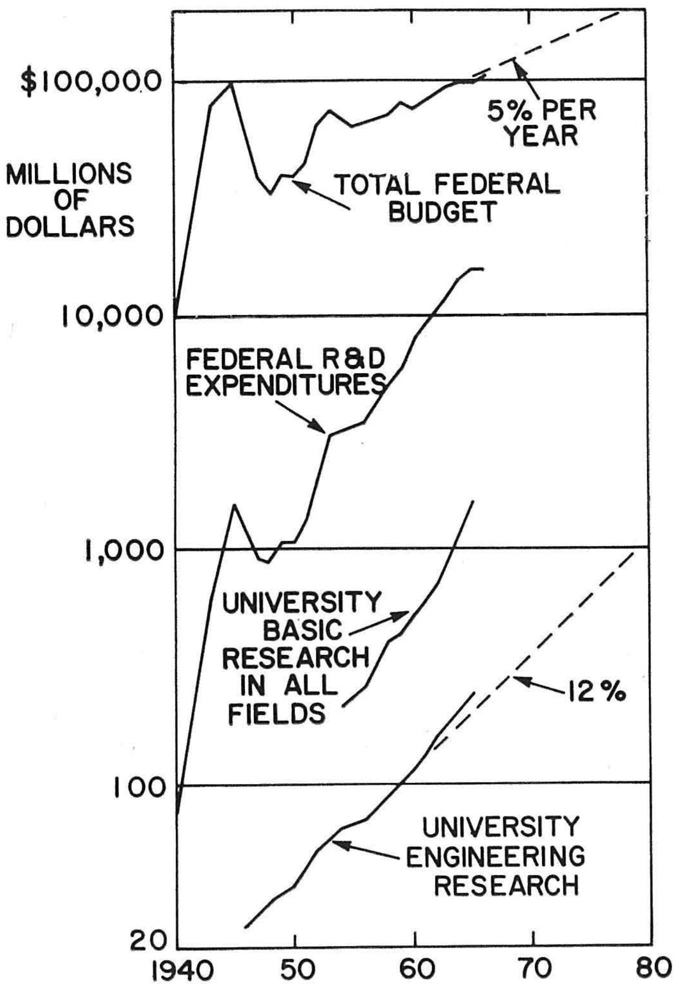



Figure D-24. Research expenditures and the federal budget.

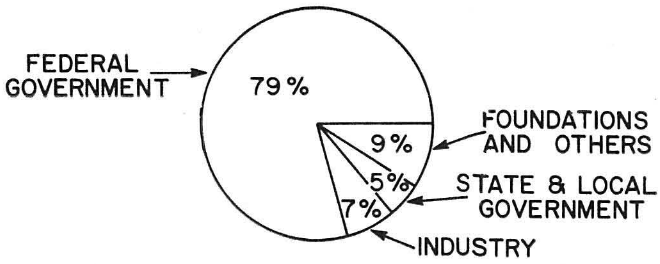



Figure D-26. Sources of support for basic research in the engineering schools (1962-63).

*Because research support is so essential in graduate engineering education, it is recommended that the federal government continue to increase its financial support of basic research in the engineering schools.*

The dollar amount of sponsored engineering research under the direct supervision of engineering faculty varies greatly from school to school, just as the size of schools varies greatly. The amount ranges from practically zero at some small schools to over $10 million at three large schools.

A comparison of annual research expenditures with output of doctor's degrees for the year 1963 shows that in engineering about $120,000 is spent in the total research program of the school for each doctor's degree granted. In the physical sciences the figure is about the same, while in the life sciences it is even higher ($150,000). These figures show clearly the large amount of financial support that is required to maintain a research program at an institution in which doctoral students are participating.

The $120,000 figure can be interpreted as the average research cost per doctorate, and while it seems like a high figure it includes various costs related only indirectly to the work of a given student, such items as overhead, pro rata of faculty and service staff salaries, capital equipment—everything. It is certainly not the incremental cost of adding a single doctoral student to an already established program. Viewing it somewhat differently, the annual cost related to producing one doctorate at the end of the year is also covering the expenses of perhaps five other master's and doctoral students working on the project; thus the annual cost per student can be considered at about $20,000 per year, including all indirect costs.

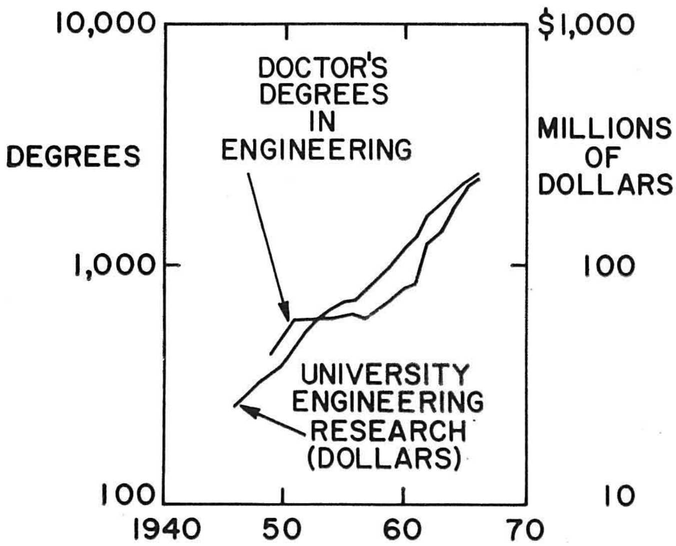



Figure D-25. Comparison of annual university engineering research expenditures and doctor's degrees in engineering.

Most of the federal research funds have been and probably should continue to be awarded on the basis of merit of unsolicited proposals from competent faculty investigators. However, there also is a need for a larger portion to be awarded to institutions, particularly to new graduate schools, for internal allocation. At the same time, quality must always be a prime consideration, even with the institutional grants, and hence before institutional grants are renewed the performance on the first grant ought to be evaluated. The national interest will not be served by continued support of low quality programs, even if some geographical distribution is accomplished. New centers of excellence will not emerge from financial support which does not require the individual institution to conduct its internal affairs with standards as high as those in institutions which have become high-quality graduate centers under competitive conditions. Thus, it is important for the federal government to differentiate between the needs for (1) support of research by highly qualified faculty wherever they may be located, and (2) initial support of new or developing institutions, especially in geographic regions where there is evidence of need.

It would also seem to be highly desirable for more of the needed increase in graduate research support to come from the private sector of the economy. With only 7% of the research support for our engineering schools coming from industry (compared to 79% from the federal government) there is an obvious imbalance. This is not to imply that there is basic dissatisfaction with the federal support of research—it has, in fact, been excellent—or that it should not continue to increase. The point is, rather, that the need for expanded support of engineering college research should draw upon all possible sources. It is also inevitable that research workers, faculty and students alike, will have a special interest in, and loyalty to, their sources of financial support, and it would be desirable—if only symbolic—for a greater portion of this identification to be oriented toward U. S. industry.

Even though the present total of industry support shows need of increase, many companies indeed are helping through grants or contracts from individual companies to individual professors or engineering schools. Some of these companies feel that they can well afford to make adequate grants of this kind, and value the direct contact with the school. We would hope for this kind of arrangement to continue and to increase.

It is suggested, however, that not all individual companies can provide the administration required for the receiving of proposals and awarding of grants, and many small companies cannot afford to make grants of adequate size. There would seem to be an opportunity for a new non-governmental agency to be established, in the manner of the National Merit Scholarship Corporation, to receive contributions from companies desiring to participate and to make research grants to engineering professors and institutions. This kind of foundation has been in operation in Germany for some time. Such an arrangement would not be intended to replace the grants from individual companies to individual schools, but would be only a supplement though hopefully a significant one. Such has been the case with scholarships—many are awarded by individual companies, many others go through the National Merit Scholarship program (see Ref. D-32).

New encouragement for industrial contributions to university research could be provided by federal legislation which would permit such contributions to education to be deductible from corporate income taxes. In 1964 U.S. corporations paid almost $24 billion in income taxes, whereas their support of research in the engineering colleges was only $7.2 million for that year, or an amount equivalent to only about 0.03% of their federal taxes. If even half of the U.S. corporations were to contribute only one-third of one percent of their earnings on a tax-free basis, we could have a ten-fold increase in corporate support of graduate research in the engineering colleges.

Industry can benefit from faculty-student research in the engineering schools, both from the availability of new graduates and new knowledge—even though both are equally accessible to competitors. Hence it seems not unreasonable for industry to support engineering school research in addition to maintaining their in-house research programs.

*It is recommended that industry increase substantially its share of the support of research in the engineering schools, as part of its program of educational support, using existing or new arrangements for grants or contracts.*

The financial support provided to individual students by sponsored research is an important by-product. This financial assistance is usually in the form of employment on research projects as research assistants. This type of support is very widespread. As shown in the next section (see Fig. D-29), 27% of all on-campus students receiving financial awards held research assistantships. The percentage is still higher (33%) for students beyond the first graduate year. Also, 62% of the 1963 engineering doctoral awardees received over $2,000 per year from sponsored projects, and 63% completed their dissertation research as part of such a project. It is obvious from these very high percentages that without such support, many graduate programs would collapse and the training of doctoral engineers would be seriously impaired.

Much has been said in recent years about the distribution of federal research support among institutions and geographic regions. The Goals project examined this subject in considerable detail and reported on it in an earlier publication (Ref. D-3). The distribution of research expenditures among the individual universities follows a pattern that is consistent with the distribution of degree output. As described earlier in Sect. 1, this distribution is based upon an underlying sociological phenomenon in which there are both large and small institutions. Furthermore, a comparison of research expenditures with doctor's degrees shows that the small schools actually have more research dollars per degree than do the large schools. The National Science Foundation has apparently given special attention to the smaller schools in the awarding of research grants and graduate traineeships (Ref. D-3).

The present geographical distribution of research support has produced concern that some regions of the U.S. are being unduly favored in the awarding of funds. When the proportion of research funds, fellowships, and traineeships is compared to other factors which characterize a geographic region (total population, engineering population, and degrees awarded), it appears that the regions with smaller populations and less well-known schools in the awarding of research grants and graduate schools are being favored (Ref. D-3).

# 10. PATTERNS OF ADVANCED-DEGREE EDUCATION

*Introduction*

The various patterns of advanced-degree education in engineering include:

(1) Full-time study on-campus

(2) Part-time study on-campus with part-time employment on-campus

(3) Part-time study on campus with part-time or full-time employment off-campus

(4) Part-time study in off-campus educational programs with part-time or full-time employment off-campus.

Choice among these possible arrangements—all of which are to be found in many locations in the U.S. today—is viewed quite differently by students and by educators. The students are primarily concerned with their financial requirements for achieving a graduate degree, while the educators are more concerned with academic conditions.

From the educator's point of view, part-time programs operate in a different pedagogical environment from traditional full-time, on-campus study, especially when the student's employment and classes are both at a location remote from the main campus of the university. However, part-time graduate programs up to the master's level are widely available, and they can render an educational service to a student population that would not be able to attend full-time. At the doctoral level, however, full-time on-campus residence is the usual pattern, though for a given student this can follow after a part-time master's program. A few companies, in fact, are using successful student performance in a part-time program—coupled with successful employment performance—as a basis for the award of fellowships for full-time doctoral study. This kind of program seems very worthwhile and should be extended to additional companies.

The Institutional Reports show that, in 1963, 53% of the graduate students were "geographically" full-time on-campus, i.e., in categories (1) and (2) above, whereas 47% were part-time. The division has varied over the years, as shown in Table D-9; there was a large growth in part-time enrollment after World War II, but since the middle '50's the full-time enrollment has grown more rapidly. Thus, the current situation is that about half the graduate students are employed off-campus at least part-time. Actually, since the foreign students have more limited opportunity for such employment, only 19% of them are so employed (see Table D-10). The percent of U.S. students employed part-time is, therefore, slightly more (52%), though still essentially half of the total.

TABLE D-9
GRADUATE ENGINEERING ENROLLMENT

| Year | Full-Time | Part-Time |
|---|---|---|
| 1948 | 55% | 45% |
| 1952 | 36 | 64 |
| 1956 | 39 | 61 |
| 1957 | 40 | 60 |
| 1959 | 43 | 57 |
| 1962 | 51 | 49 |
| 1963 | 53 | 47 |

TABLE D-10
GRADUATE ENGINEERING ENROLLMENTS
(AUTUMN 1963)

| | Full-time | Part-time | Total |
|---|---|---|---|
| All students | 53% | 47% | 100% |
| U. S. citizens only | 48% | 52% | 100% |
| Foreign students only | 81% | 19% | 100% |

*Industry Viewpoints*

From the employer's viewpoint there is a severe compromise necessary between short-term and long-term goals. The employer may need the daily services of the young engineer, and yet he knows that he should invest in advanced education in order to derive a higher level of performance later. He would really prefer to hire the engineer after his advanced degrees are completed, but he may fear that if he doesn't hire the young man as early as possible, some other employer may do so. Different classes of employers reach this compromise differently, depending to some extent on the importance they attached to advanced-degree education. Frequently they may really be more interested in continuing engineering studies for their employees, as described in Section 13, but use available degree programs as a means to this end.

In the Industry-Government Survey some interesting data were acquired as to the extent and diversity of employer policies, as perceived by engineering employees. These are shown in Fig. D-27 for all employers together, and then according to industry classification in Figs. D-28 and D-16. Industry differences are clearly substantial, as shown in these figures.

Additional insight into industry differences was obtained by the Industry-Government Survey wherein personnel representatives were queried as to employer policies (Ref. D-16). On the matter of encouraging advanced-degree work it is worth noting that on the average, more personnel men (42%) thought their employers gave "much" encouragement of advanced-

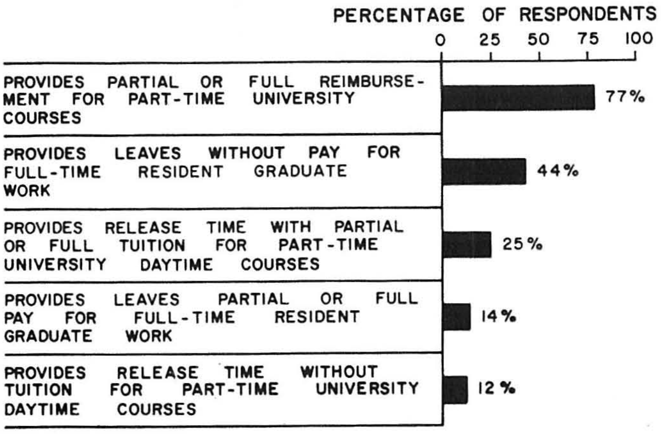



Figure D-27. Percentage of graduates reporting various policies on continuing education in the organizations in which employed in 1964.

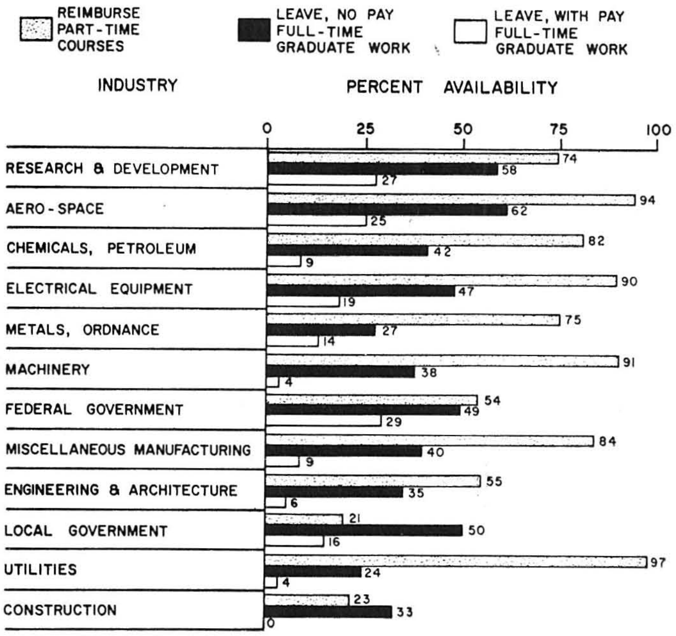



Figure D-28. Percentage of graduates in different industries which reported various educational policies in the organizations in which employed.

TABLE D-11

PERCENTAGE OF ENGINEERS RECEIVING GRADUATE EDUCATION COMPARED TO ENGINEERS EMPLOYED

| Industry | Percent of Engineers (Non-doctorates) Receiving Graduate Education |
|---|---|
| Research & Development | 23% |
| Aero-Space | 21 |
| Electrical Equipment | 20 |
| Machinery | 12 |
| Metals, Ordnance | 9 |
| Misc. Manufacturing | 9 |
| Federal Government | 8 |
| Chemicals, Petroleum | 7 |
| Utilities | 6 |
| Engineering & Architecture | 5 |
| Local Government | 3 |
| Construction | 1 |

degree work for engineers than was perceived by the engineers themselves (only 23%). Nevertheless, the views of these personnel representatives varied among the different industry groups and the general ranking of the groups is consistent with the previous illustrations.

Further evidence of industry differences can be seen in Table D-11 which gives the percentage of engineers *actually receiving education* at the graduate level compared to the total number of engineers employed, excluding those who already possess the doctorate.

### *Full-time, On-campus Programs*

From the student viewpoint, full-time, on-campus study permits more rapid progress toward a degree, but usually with more stringent financial conditions. Adequate financial support for on-campus graduate students, both in number and size of awards, is a necessity to insure that well-qualified students may continue their education, and that their numbers be sufficient to meet our national needs. Graduate scholarships, fellowships, and traineeships usually provide financial aid while permitting full-time study. Teaching and research assistantships provide valuable work experience while permitting substantial time for study. The distribution among types of financial awards, for both U.S. students and foreign students combined, is depicted in Fig. D-29. In general, support through research assistantships is much greater after the first year of graduate work (an increase from 20% to 33%). During the first year foreign students have a lower percentage of traineeships and teaching assistantships than U.S. students, but about the same percent are supported by fellowships, scholarships, and research assistantships. After the first year, foreign students are supported to a lesser extent than U.S. students by fellowships and scholarships, and to a much greater extent by research assistantships.

Another consideration in financial support for on-campus graduate students is the source of funds. In

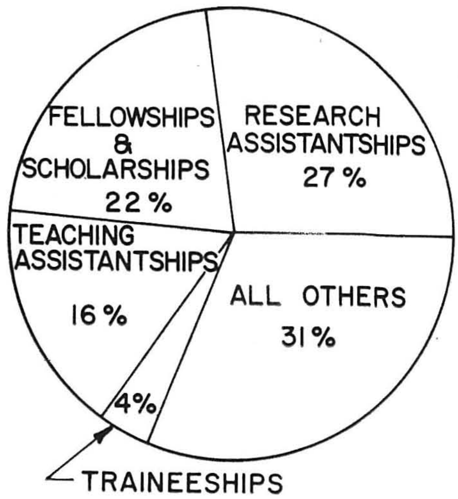



Figure D-29. Types of financial awards for on-campus ("geographically full-time") graduate students, 1962-63.

1962-63 the number of graduate student awards according to source of funds on a percentage basis was as shown in Fig. D-30. It is important that a balanced growth in fellowship awards be maintained, both from governmental and private sources. As might be expected the publicly-controlled schools have a higher percentage of fellowships from state and municipal funds than do the privately-controlled schools (22% versus 6%). They also have a relatively greater dependence on federal funds (41% versus 29%). The privately-controlled schools derive about two-thirds of their fellowships from private funds, the publicly-controlled schools about two-thirds of theirs from public funds (federal plus state and municipal).

In summary, if full-time programs are to remain attractive to the best students, adequate student financial support must be maintained. Since half the awards for scholarships and fellowships are provided by private sources, this presents a challenge to foundations, corporations, and individuals for increasing support. Furthermore, engineering faculty must continue to develop new full-time advanced-degree programs to accommodate the expected national growth. Quality must be maintained and improved at the same time.

*Off-campus Employment*

A pattern of part-time off-campus employment in industry or government may have the disadvantage to the student of slower progress toward a degree, but this is offset by the higher salaries and the opportunity to commence professional work with an employer of his choice. When such an employer is situated near a graduate engineering school, feasible arrangements have been established for the student to pursue either a daytime-release or an out-of-hours program of graduate courses, depending upon which is available and what the employer's policy may be.

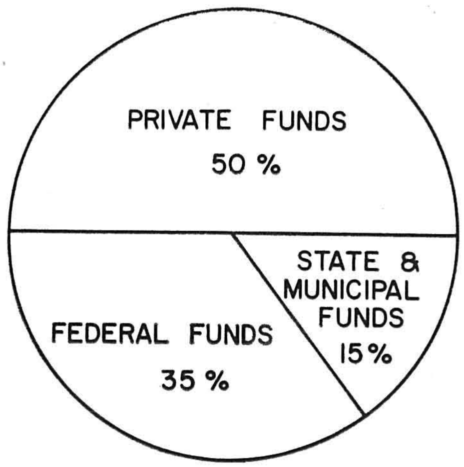



Figure D-30. Sources of financial support (number of awards) for on-campus graduate students, 1962-63.

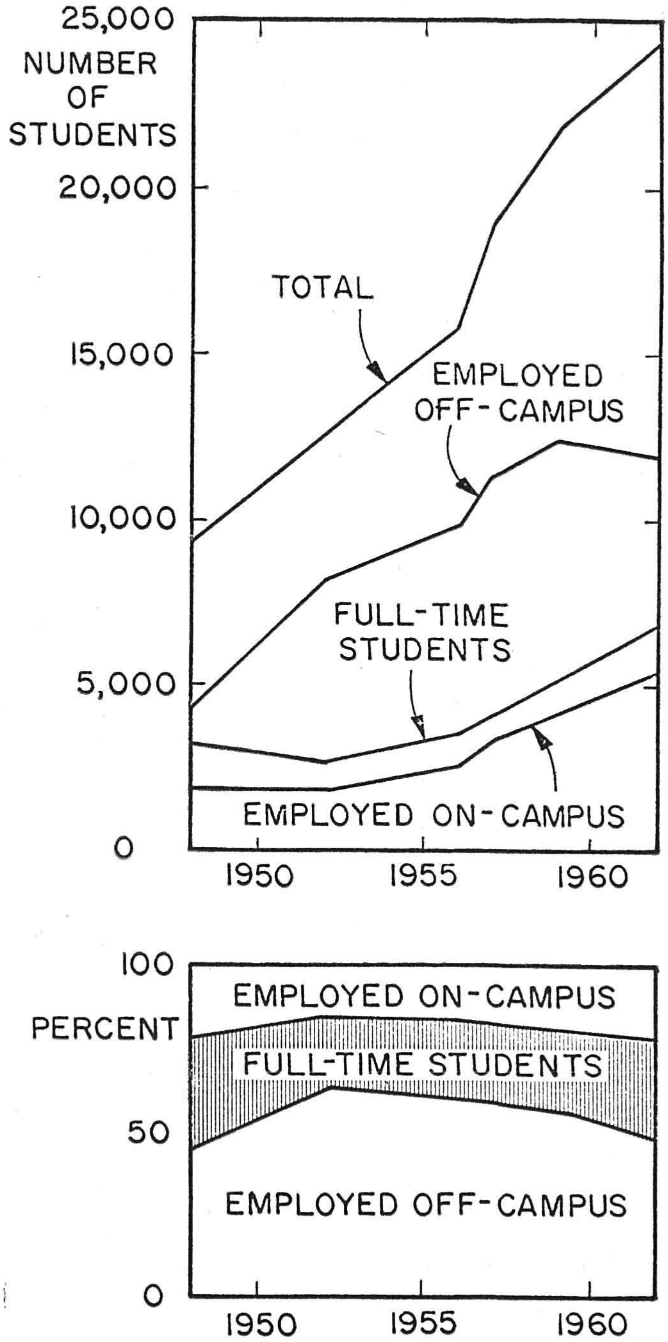


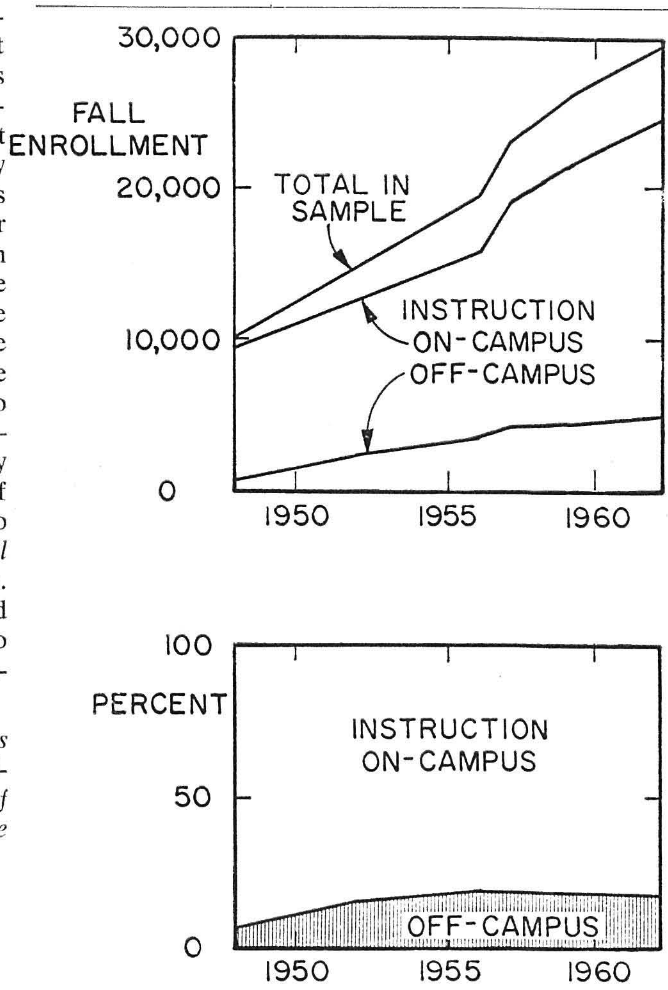

Figure D-31. Employment of graduate students in engineering (instruction on-campus).

Part-time graduate education to accommodate students employed off-campus grew rapidly in the ten years following World War II, as shown in Fig. D-31, and, while subsequently the relative growth has slowed substantially, there is no reason to believe that the end has been reached. These programs have grown in response to local needs, and it is clearly in the national interest that the educational system be responsive to these needs.

The best arrangement for safeguarding of quality for the students and their employers is provided in daytime-release programs, where the students attend regular graduate classes with the full-time students. The students thus have access to the best of the regular faculty, and the academic pace is maintained by the full-time students.

From the pedagogic standpoint, the pattern of part-time graduate study has the major disadvantage in that the student has competing demands on his time. He is usually employed at a nearly full-time rate as a responsible engineer, and as such is caught up in project schedules, travel, etc. These responsibilities are usually more demanding than are those of an on-campus teaching or research assistant. There is less time for library study, conferences with faculty, and discussion with other students. The consequences are to some degree measurable; skills and factual knowledge can be tested in the individual course examinations, and the quality of learning can be kept high for both the full-time and the part-time students. But there are also intangible advantages of full-time on-campus study—relating perhaps to attitudes and habits engendered by the environment. The lack of a measure of the results of these advantages makes it difficult if not impossible to prove their existence. It cannot even be shown that *all* full-time students have benefited from these advantages. Thus, in view of the compelling desire of students and employers for part-time arrangements, it would seem to be a reasonable goal to encourage these as a supplement to the full-time programs.

*It is therefore recommended that engineering colleges establish and maintain high-quality part-time advanced-degree programs for on-campus study by employees of nearby industry and government agencies, when the local situation justifies it.*




| SAMPLE AS A PERCENT OF U.S. ENROLLMENT | | | | | |
|---|---|---|---|---|---|
| 1948 | 52 | 56 | 57 | 59 | 1962 |
| 66 | 73 | 76 | 82 | 76 | 67 |

Figure D-32. Enrollment in off-campus instruction in a sample of 51 institutions which offered such instruction during the period 1948 to 1962.

### *Off-campus Instruction*

Since part-time programs are more difficult to arrange if the employer is located at some distance from the nearest graduate school, many schools give off-campus courses for degree credit. The number of students enrolled in such courses grew substantially following World War II, as shown in Fig. D-32. Although it is possible for a student to obtain a master's degree by taking such courses, some schools require that some minimum number of classes must be taken at the main campus. It is the general practice among engineering schools not to award doctor's degrees solely for off-campus study. For instance, some schools permit courses to be taken off-campus but require that the dissertation research be performed on the campus under the supervision of a qualified professor.

Of the 146 schools awarding the master's degree in 1964 many offered a limited number of graduate courses at off-campus locations, but only the 30 listed in Table D-12 were known to provide the possibility for a student to earn completely his master's degree at an off-campus location.

A few examples of off-campus programs can be mentioned in order to indicate how such programs are operated. (1) The University of Michigan has a Center for Graduate Study at Flint, Michigan, with master's programs in several branches of engineering. The courses are equivalent to those at the main campus (Ann Arbor, Michigan) and they are taught by regular engineering faculty who commute. The programs are subject

**TABLE D-12**

**UNIVERSITIES OFFERING MASTER'S PROGRAMS AT OFF-CAMPUS LOCATIONS (1964)**

| | |
|---|---|
| University of Alabama | Northeastern University |
| University of Arkansas | Ohio State University |
| Poly. Inst. of Brooklyn | Oregon State University |
| U.C.L.A. | Penn. State University |
| University of Colorado | Purdue University |
| University of Delaware | Rensselaer Poly. Inst. |
| Drexel Inst. of Tech. | University of Rhode Island |
| University of Florida | University of Southern Calif. |
| University of Idaho | Syracuse University |
| Johns Hopkins University | University of Tennessee |
| University of Kansas | USAF Inst. of Tech. |
| Louisiana State University | University of Washington |
| University of Michigan | Washington State University |
| Michigan State University | University of West Virginia |
| University of New Mexico | University of Wisconsin |

to the same regulations as on the main campus, and students are admitted through the same procedures and according to the same standards as on the main campus. (2) The University of Southern California gives courses at a number of off-campus locations including Edwards Air Force Base and Norton Air Force Base. Most of the persons enrolled off-campus are professional engineers in aerospace and electronics industries, and usually they are required to take some courses on-campus before they can get a degree. Two exceptions, however, are Edwards Air Force Base and Norton Air Force Base, where all the courses can be taken off-campus. Students must be admitted in the same manner as a regular campus student if they wish to pursue a degree. (3) A graduate center is operated at Hartford, Connecticut by Rensselaer Polytechnic Institute. This center is a "branch campus" which now awards master's degrees and plans to give the doctor's degree in the future. The faculty consists of a full-time resident faculty plus a part-time faculty, the latter being larger in numbers than the former. The rules and regulations pertaining to academic standards, admissions, degree requirements, etc., are the same as on the Troy campus. The students are mostly industrial employees in the Hartford area. (4) The Polytechnic Institute of Brooklyn operates a similar center on Long Island; the "branch campus" exists in buildings erected for that purpose. Both master's and doctor's degrees are awarded, and there are both part-time and full-time students in attendance (over 1,200 total).

There is a real opportunity for innovation to facilitate high-quality off-campus instruction. An example is the so-called GENESYS installation of the University of Florida, which provides several off-campus centers linked by closed-circuit television with the main campus and with each other. Classes can originate at any of the remote centers as well as in classrooms on the main campus. Remote classes are connected by one-way video and by two-way audio to permit student questions and discussion.

From the educator's view, the matter of academic standards in part-time programs at off-campus locations warrants special attention. Selection of students and selection of faculty are the two dimensions that produce the wide range of quality of graduate programs, whether on-campus or off-campus. It is typical for the schools listed in Table D-12 to require the admission of students to graduate standing as though they were being admitted for study at the main campus. Selection of faculty is another matter, however. While many of the off-campus centers have a few resident faculty—or a few regular faculty who commute—and while it is claimed that these are appointed with the same criteria as though they were regular faculty on the main campus, there seem to be two aspects that are different—neither of them precisely measurable. First, there is the proportion of regular faculty as opposed to lecturers or adjunct professors. Both are used in programs on-campus or off-campus, but for on-campus programs most are regular professors. Most of the off-campus instructors may be engineering employees of the employers of the students being taught, rather than being regular faculty of the sponsoring university. They may be qualified in the subject matter, but may not be "calibrated" on standards of student performance, degree requirements, etc. Secondly, the selection process for regular faculty is usually quite rigorous, whereas it may not be so for off-campus instructors who do not come under tenure, etc.

When the off-campus program is conducted by an established university, quality is monitored both by the university itself, which will guard the prestige of its degrees, and by the regional association responsible for accrediting the university. Quality will inevitably be variable among such programs, but in our system quality is widely variable even among full-time resident programs, and employers know this. It is believed that there is no hope of "policing" completely such off-campus programs on a national basis, particularly when there are situations where there is a strong local demand, which simply will be met in one way or another.

One suggestion is that degrees awarded on part-time programs, particularly those with all instruction off-campus, should carry a special designation to indicate the nature of the program, such as M.S. (part-time), M.S. (off-campus) or M.S. (external). Thus far the universities having such programs have not elected to make such distinctions in the degree title, though presumably transcripts give information as to the location and nature of the programs. They seem to regard their programs as comparable in scope and quality, even if not identical in environment.

*With the preceding considerations in mind, it is recommended that new techniques and arrangements be devised for extending high-quality advanced-degree education to engineering students employed at locations remote from established campuses.*

## 11. DEVELOPMENT OF AN ADVANCED-DEGREE PROGRAM

Many engineering schools are now either just beginning to engage in graduate programs, or else, having had small graduate programs, are ready to enlarge them. Figures D-8 and D-9 show the numbers of new schools that have entered upon graduate work since 1950. New schools have been continually entering the picture, and have been growing in size. Their relative positions in the spectrum of graduate schools have shifted in the process. The continued growth in higher education (portrayed in Figs. D-1 and D-2) indicates a favorable climate for the entry of new schools into the graduate field. In planning and arranging for these changes, it is helpful to consider how increases in graduate education have occurred in the past.

### *Study of Four Sample Schools*

As an indication of what has been done in the past by schools that grew from small size to a well-established position of good reputation, the Goals project conducted a study of four sample graduate schools. These schools were selected, somewhat arbitrarily, from among a

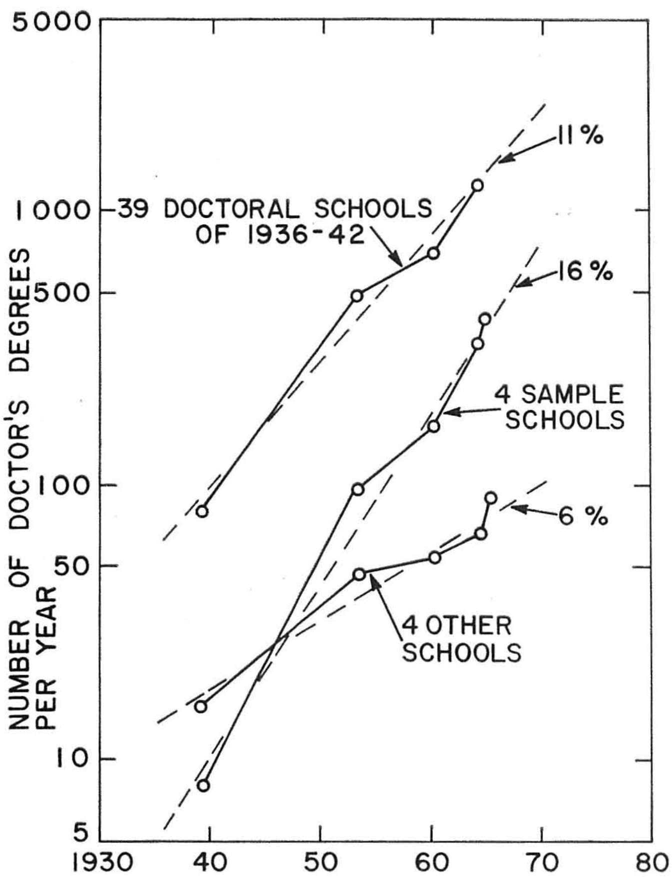



Figure D-33. Growth of schools that awarded a doctor's degree during the period 1936-42. (Note: The points plotted on the graph represent annual averages for the time periods shown in Table D-13.)

larger group of schools that had undergone substantial and noteworthy growth during the past twenty years or so. The four schools can serve as examples of successful growth and development, and information about these schools can be more useful to other schools that are now or soon will be developing graduate programs than would be advice in the form of generalized platitudes.

Through campus visits and interviews, it was possible to obtain much more information about the current methods of operation and the recent history of these growth schools than would otherwise have been available. As a matter of particular attention, an attempt was made to determine what special persons, policies, or events were responsible for the successful growth of these schools.

The selection of the sample schools was made after considering a great many factors. An initial consideration was the matter of quality, as perceived by two groups. The first group included the faculty members of the Institutional Study Committees who responded to Information Document No. 4. One of the questions in that document (Question 9.1b) asked for rankings of schools (excluding one's own) for various curricula, naming the five institutions which would be recommended to one of the best senior students in engineering for him to consider as a school to attend for graduate study. While recognizing that "opinion polls" are not necessarily accurate, it was nevertheless quite clear from the response to this question that certain schools are widely held in high regard by engineering professors. In compiling the responses the schools were first ranked on the basis of all curricula taken together, and then on the basis of only three curricula in which they ranked highest. The latter ranking would eliminate bias in favor of the large schools with many curricula. Nevertheless, the ranking of the schools was essentially the same whether all curricula or only three were used. The second group of persons whose perception of the quality of graduate schools was studied was the student awardees of NSF Graduate Fellowships. These students receive their fellowships in national competition and are free to choose the graduate school they will attend. Thus, a ranking of schools according to their choices gives a measure of student perceptions, influenced of course by their faculty advisors.

Having then a list of schools of high quality, the growth history of the schools during the last 25 years was examined. During the seven-year period 1936-42 there were 39 schools that awarded a doctor's degree in engineering, including all of the schools that are large doctoral schools today. The average rate of growth of the 39 schools was approximately 11% per year as depicted in Fig. D-33. However, some schools grew much faster than the average, and such schools were considered to be of interest in the sample school study. In the figure is shown also the growth history of those four schools which were finally selected as the sample schools; their annual growth rate was about 16%. By way of contrast, a graph for another four schools, also of high quality, from the total of 39 is shown; these four schools had a growth rate of only 6%.

The schools were examined also on the basis of all other factors for which data were available, until the list of possible sample schools was brought to about ten schools. Then it was decided to make some arbitrary decisions in order to reduce the group to four. One of the ten, M.I.T., the largest school, has for many years been in a class by itself, being highest ranked in about every category. For this very reason it was decided not to include M.I.T., since it seemed doubtful that any small school could relate itself to such a long established institution. As another example of the type of choice that had to be made, it was found that the University of Illinois and Purdue University were quite comparable in many respects. However, since they are situated near one another geographically, and since both are large publicly-controlled schools, it was decided not to include both, and Illinois was selected arbitrarily. The final selection included two privately-controlled and two publicly-controlled schools, one of each kind being in the east or midwest, and one of each kind being in the far west. The four sample schools were as follows: University of California (Berkeley), Carnegie Institute of Technology, University of Illinois, and Stanford University.*

* Subsequent to the sample school study the American Council on Education published a report (Ref. D-15) in which graduate schools were ranked on the basis of the quality of their faculties and the effectiveness of their graduate programs. Within engineering the rankings of the ACE study agree well with those of the Goals study, and three of the four sample schools lie within the first five places of the ACE rankings.

Some degree data pertaining to the sample schools are given in Table D-13 which gives the growth in the number of doctor's degrees awarded. The four schools averaged only two doctor's degrees per year in 1939, but grew to an average of 98 degrees in 1965.

TABLE D-13
ANNUAL NUMBER OF DOCTOR'S DEGREES FOR SAMPLE GRADUATE SCHOOLS

| Institution | 1936-42 | 1950-56 | 1958-62 | 1964 | 1965 |
|---|---|---|---|---|---|
| Univ. of California (Berkeley) | 1 | 17 | 32 | 68 | 115 |
| Carnegie Inst. of Tech. | 1 | 18 | 25 | 43 | 41 |
| Univ. of Illinois | 4 | 39 | 64 | 131 | 109 |
| Stanford University | 2 | 22 | 47 | 94 | 128 |
| Total | 8 | 96 | 168 | 336 | 393 |

(Note: When a time span is indicated, the number of degrees is the annual average during that period.)

All available information pertaining to the four schools was assembled and studied by the Goals Staff; the information included the school's Institutional Reports, catalogs, and statistical data. Interviews were conducted with many persons at each school, including the deans, some department heads, and some faculty.

### *Observations*

Several major factors emerged from interviews that were conducted at each of the sample schools. Perhaps the most important factor, one that was reiterated at each school by all of the persons interviewed, was the importance of individual initiative on the part of one or more highly motivated, key persons. These persons actively developed graduate programs and initiated research, beginning in the 1940's. At each school the names of such key persons were mentioned repeatedly as principal motivating factors. For instance, at two of the schools there was an aggressive dean who gave strong personal leadership, set new policies, and hired research-minded faculty, sometimes over considerable objection from the departments. At another two of the schools, a department head was hired for a major department for the specific purpose of developing research in that field. In each case, he later was appointed dean and continued his endeavors on a broader basis.

At all four schools the persons mentioned above, who were either deans or department heads, instituted clear-cut policies encouraging graduate study and research. For example, the teaching of graduate courses and the supervision of doctoral students were given extra weight in determining teaching loads. At one school a graduate course was weighted one-third more than an undergraduate course when determining faculty work loads; at another, a factor of one-fourth more was used. Furthermore, faculty persons conducting research were given lighter teaching loads. For example, at one school a policy was instituted to the effect that supervising three research students was equivalent to teaching one course; at another school, it was two students.

The deliberate encouragement of research was evident also in the policies for hiring faculty. Research-minded professors, normally having a doctor's degree, were hired. At one school, there were many retirements during the 1940's, and it was decided that all of the replacements should be research faculty.

The important idea that became clear from all four schools was that the policies described above were set by intention about 20 years ago, long before the era when federally sponsored research became widespread. In this respect the similarities among the four schools were quite noticeable. Furthermore, the policies were not always popular, and they were contrary to prevailing notions at many other schools.

In no case did the growth of the school begin as a consequence of special financial aid, either from the federal government or from another source. Instead, the key persons succeeded in initiating research, and encouraging others to do the same, by using their own and outside resources as best they could. A few years later when federal support began to enter the picture, all four of these schools had already become established in research and moved ahead swiftly in the new era of federal support. The result was their large growth during the 1950's and 1960's.

Teaching loads at the four schools today show considerable similarity. At all of the schools a typical load for a full professor is as follows: (1) one undergraduate course; (2) one graduate course; (3) several research students; and (4) other professional duties (such as committee work). At three of the schools the teaching load is further reduced to only one course when there is external financial support of research that can be used to offset part of the professor's salary.

Although "graduate faculty" were officially designated at one of the institutions, there seemed to be no conspicuous separation between graduate and undergraduate faculty at any of these schools.

A good undergraduate student body from which to select the best graduate students was helpful at these schools when graduate programs were starting up. Later, when the programs became established, many students were attracted from other schools.

*In all cases the strength and size of the undergraduate program have continued to flourish as the graduate program grew.* At two of the institutions the undergraduate population is quite large.

It should not be inferred that the sample schools represent the only possible model for developing a graduate program, nor even that success will be guaranteed by following this model. *Perhaps the primary lesson to be learned from this study is the importance of outstanding faculty people who have clear goals.* Financial support, curriculum arrangements, and other such matters follow later; they do not, however, serve as the prime movers. Finally, *a period of ten to twenty years is needed to accomplish the development of a well established advanced-degree program.*

*In summary, it is important that engineering schools respond to the growing national need for graduate study and the opportunities to develop new or enlarged advanced-degree programs of high quality. To those* *schools now considering the introduction of graduate programs, it is recommended that this be done with a realistic understanding of the important role of academic leadership, and with an appreciation of the need for adequate time to build up faculty, students, and resources.**

## 12. ACCREDITATION OF ADVANCED DEGREES

### Accreditation Policies

*Accreditation of advanced degree programs at the graduate level has been under discussion for many years.* Even the first Annual Report of ECPD (1933) stated that both undergraduate and graduate curricula shall be accredited. Of course, the general policy of ECPD has been to accredit only the basic engineering program, leading to what they call the "first professional degree," which can be either the bachelor's or master's degree. This is the only type of accrediting for which ECPD has been approved by the National Commission on Accrediting. If ECPD were to accredit advanced degrees, additional approval would be required.

Some impressions of the interest of ECPD in graduate accreditation over the years can be gained from the following excerpts from the Annual Reports of ECPD: "The Committee has confined its activities to undergraduate curricula and has not yet even planned an approach to the accrediting of graduate curricula." (1939); "ECPD has planned for a number of years to extend its accrediting activities to graduate work in engineering. The rapid increase in graduate work since the end of the war makes it particularly important that prompt attention be given to this area." (1948); "The Sub-committee on Graduate Education has continued to consider the matter of the possible function of ECPD in the area of graduate engineering education." (1950); "A matter of increasingly active concern of the Education and Accrediting Committee is the accreditation of graduate programs." (1962). Concurrent with the discussions within ECPD there has been much interest and concern over graduate accreditation on the part of others, and arguments pro and con have been put forth. (Much of the history and background of engineering accreditation, with particular reference to graduate accreditation, has been documented by the Goals Study in Ref. D-34.)

The principal factors underlying the ECPD discussions over the years seem to be these: first, a recognition that graduate study was being taken by a larger fraction of engineers and was becoming more clearly established as a prerequisite for many kinds of engineering work; and second, an impression that graduate education at the master's level had a wide range of standards, perhaps even wider than in undergraduate engineering when ECPD accreditation began in 1932. Thus, it is not surprising that concern about graduate accrediting has existed in engineering.

*When other professions are compared with engineering, it appears that engineering has actually been quite unique in maintaining its focus so strongly on undergraduate accreditation.* Examples are shown in Table D-14, which is excerpted from Ref. D-34.

Recommendations for the basic engineering degree have already been discussed in Part C and need not be repeated here. The principal feature of that discussion is the recognition of an increasing emphasis on the master's degree as the basic engineering degree. For those schools where this change occurs, if it has not already occurred, the first accredited degree will automatically become the master's degree. This step is inevitable because we take it for granted that we are operating within the general principle that the engineering profession (as with any other profession) has an obligation to control the quality and amount of educational preparation for entrance into the profession.

The present ECPD policy of accrediting that degree which they call the "first professional degree" (and which we have called the *basic* degree) has worked out well over the years. It permits considerable flexibility for individual arrangements—for instance, accrediting can be at different degree levels at different schools, or even at different levels within the same school for different curricula. Also, it appears that accrediting can be either by curriculum or by school under this arrangement. *Therefore, we have recommended that ECPD continue to focus its accrediting on the basic or "first professional" degree.*

TABLE D-14

ACCREDITING IN VARIOUS PROFESSIONAL FIELDS

| Profession | Accredited Programs |
|---|---|
| Architecture | 5-years minimum |
| Business Administration | Bachelor's and Master's |
| Chemistry | Bachelor's |
| Dentistry | Professional school (usually 6 yrs. total) |
| Engineering | First professional degree (usually 4 or 5 years) |
| Forestry | Bachelor's and Master's |
| Landscape Architecture | Bachelor's |
| Law | Professional degree (usually 6 yrs. total) |
| Librarianship | Master's |
| Medicine | Professional school (usually 7 or 8 yrs.) |
| Nursing | Bachelor's and Master's |
| Optometry | Professional degrees (usually 6 yrs. total) |
| Pharmacy | Bachelor's (5 yrs.) |
| Psychology | Doctor's (in two areas) |
| Public Health | Master's and Doctor's |
| Social Work | Master's |
| Teacher Education | Bachelor's, Master's, and Doctor's |
| Theology | Professional school (usually 5 to 7 yrs.) |
| Veterinary Medicine | Doctor's (usually 6 yrs.) |

* For additional discussion see Ref. D-33.

### *Accreditation of Advanced Degrees*

The possibility of accrediting either curricula or schools *beyond* a basic degree program presents difficulties because there is no consensus of the engineering profession as to the *content* of advanced degree programs. Therefore, until such time as a more clear need develops, or until a consensus as to suitable requirements develops, *we recommend that for the present there should be no accreditation of second or higher professional degrees in engineering.* In the meantime, it seems more desirable to maintain the greatest possible freedom for schools to develop new advanced-degree programs.

At the present time the regional accrediting associations are exploring the possibilities of accreditation of institutions for graduate study (see Ref. D-34), and at least one association (North Central) is now conducting graduate accreditation. Engineering educators should work to strengthen the regional associations as they extend their coverage of institutional accrediting to include graduate as well as undergraduate capabilities, because it seems desirable that the engineering profession itself should not undertake graduate accrediting in engineering until graduate *institutional* accrediting is fully established in all regions, with particular attention to coverage of off-campus programs of the institutions. An exception would be the accrediting of graduate engineering instruction which comprises part of the recommended five-year basic engineering curriculum.

# 13. CONTINUING ENGINEERING STUDIES

### *Purposes and Policies*

It is clear that now, and in the future, basic engineering education cannot presume to teach students "all they need to know." Accordingly, the profession, and academic institutions which serve it, must look forward to a growing activity in *continuing engineering studies* as a distinct educational function, outside of *advanced-degree programs.* This is not merely a matter of dealing with current obsolescence, retreading, retraining, or any of the other popularized versions which have been developed, sometimes almost frantically, to satisfy urgent localized needs. It is rather a matter of establishing and maintaining an entirely new dimension of personal development throughout the engineer's career. It is a matter of taking a long-range look at the ever increasing rate of technological change, and then deciding what now needs to be done to assure the continual effectiveness of the profession in the 1970's and beyond. In this sense, the limited activity of educational institutions, even in recent years, under the broad title of "continuing education," cannot be considered as adequate for the need and service that is being considered today.*

*What is urgently needed for the future is a more direct provision for maintaining the currency of all members of the profession no matter what the year of graduation and regardless of the degree level at which the individual enters or re-enters engineering practice.* In the words of the Joint Advisory Committee: "The future of the engineering profession will depend to a considerable extent on the demonstrated competence of individual engineers to make optimum use of the latest scientific and technical knowledge in dealing with current and future problems. Participation in programs of continuing engineering studies will ensure that such competence can be maintained."

*The objective of continuing engineering studies is the specific enhancement of the competence of the individual as a practicing engineer, rather than the attainment of an additional academic degree.* This dimension of engineering education must expand and achieve new levels of effectiveness. It differs markedly from the traditional "academic ladder" of successive degree levels in formal education. It might well be termed the "career ladder," a sequence of more individualized studies pursued at various times outside of degree programs, and selected principally for the independent purpose of career extension and stimulation. This "dual ladder" concept is illustrated in Fig. D-34, which shows on the left that the academic institutions alone are responsible for the degree ladder, but are partners with industry, government, and the engineering societies in the broader career ladder activities. Dual involvement of the educational institutions is to be expected, because the greatest amount of educational experience and teaching talent is to be found in faculty groups. At the same time, excellent teaching talent will also be found among engineering practitioners. It is essential, therefore, that all groups cooperate in providing the necessary expertise wherever it resides.

In accordance with the functional distinctions outlined in Section 3, continuing engineering studies relate primarily to the updating, diversifying, and broadening aspects of advanced engineering education. Suitable recognition for achieving these purposes should be provided, but it seems questionable, for instance, to

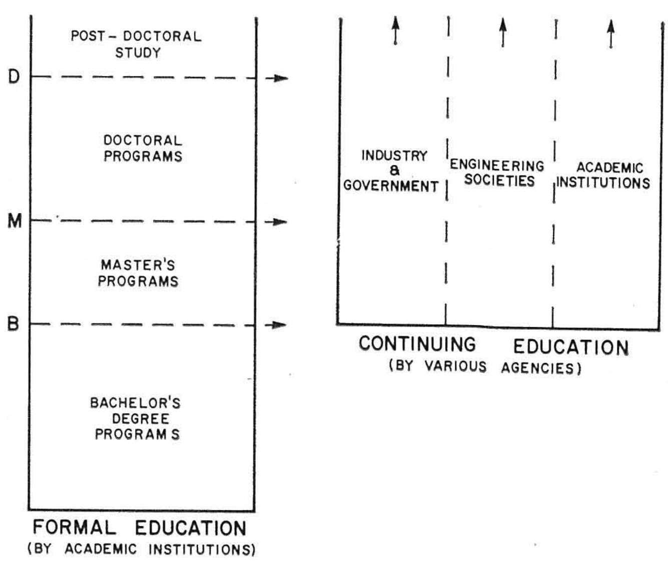



Figure D-34. Dual roles of formal and continuing education.

* Much of the material in this section is based upon the Report of the Joint Advisory Committee on Continuing Engineering Studies (Ref. D-17), and the assistance of Dean Cornelius Wandmacher, who was a member of that Committee as well as of the Graduate Board of Analysts of the Goals Study, in the preparation of this section is gratefully acknowledged.

grant an advanced academic degree merely for updating a bachelor's or master's degree. Nevertheless, many students (and their employers) in attempting to fulfill what is really a need for continuing engineering studies will seek graduate credit courses from a university. While it is true that certain graduate courses may incidentally assist in meeting a particular occupational need, generally they are not designed for this purpose. ECPD believes that a well-organized recognition system is needed and has formulated a plan for carrying this out at some future date when other considerations have been resolved (Ref. D-35).

Dominant characteristics of successful offerings of continuing studies, from the point of view of educational institutions, appear to be that they are:

(a) Of service to those who have completed at least a baccalaureate degree program and who have completed the introductory orientation and training program normally provided by an employer;

(b) Designed for somewhat heterogeneous groups, i.e., admission standards are based on a broadly recognized combination of education, experience, and maturity rather than on specific prerequisite academic credit—students may have degree backgrounds of varying levels and majors;

(c) Related to an identified immediate, or foreseeable, occupational need;

(d) Keyed to have a stimulating effect on career development;

(e) Presented by instructors, either from academic institutions or from the field of practice, whose most outstanding characteristic is command of a particular knowledge or skill;

(f) Offered under various patterns of group meeting schedules, usually involving substantial concentration on the selected subject;

(g) Given at locations and at times generally selected to accommodate the practicing engineer.

Participation in such studies will occur between, or after, all degree levels, and often will continue well beyond the age when most men would consider entering formal degree programs.

A variety of continuing engineering studies has been available in many schools in the form of short courses, conferences, part-time programs in advanced study, evening and extension programs. The programs vary from occasional special programs to regular or seasonal offerings.

The highest quality faculty members are needed as leaders for effective planning and presentation of such programs. Not all faculty members will wish to accept such assignments, but for those who do, a policy of full recognition of service as a part of regular institutional responsibility is highly desirable.

Industry, government, academic institutions, and engineering societies have a substantially unfulfilled obligation in meeting the critical technical need for an organized and comprehensive system of continuing studies.

It is clear that not only is there a great need for maintaining minimal competence through continuing professional studies but also that a greatly enhanced emphasis on continuous increase of professional competence and excellence has the potential to become a major hallmark of the engineering profession.

*Organizational Policies*

Some of the arrangements used by companies to encourage continuing studies on the part of their engineers were described in Section 10 (see Fig. D-27). Over three-quarters of the engineers indicated that their organizations provide partial or full reimbursement for part-time university courses; 44% indicated their organizations had a policy of providing leaves without pay for full-time graduate work; 25% provided released time for taking daytime courses; and so forth.

The extent to which such educational opportunities are available depends upon the type of industry, local educational facilities, and individual situations. Tuition reimbursement plans seem to be more common in utilities, aerospace, machinery, and electrical equipment industries than in local government and construction. Full-time graduate work, with and without pay, is most likely to exist in the Federal Government, research and development laboratories, and aerospace industries; whereas it is least likely to exist in construction, machinery, utilities, chemical industries, etc.

Perhaps more important than policies is the number of engineers actually participating in programs of continuing studies. Among the engineers in the survey, 54% have received or are now receiving support for such continuing studies, as shown in Table D-15.

**TABLE D-15**
**CONTINUING ENGINEERING STUDIES BY INDUSTRY AND GOVERNMENT**

| Industry or Government | Percent of Engineers who have received or are now receiving noncredit education |
|---|---|
| Utilities | 66% |
| Federal government | 62 |
| Aerospace | 59 |
| Electrical equipment | 59 |
| Misc. manufacturing | 53 |
| Chemicals, petroleum | 52 |
| Machinery | 51 |
| Local government | 50 |
| Metals | 45 |
| Engineering and architecture | 43 |
| Construction | 41 |
| Research and development | 39 |
| All industries | 54 |

*The Goals study recommends that engineering schools recognize more fully the place of continuing studies as a distinct category in the spectrum of engineering education, and that wherever possible they provide additional leadership in the planning and offering of programs of continuing studies as part of normal institutional activity. It is also recommended that engineering schools cooperate to a much greater extent with industry, government, and the engineering societies in programs of continuing engineering studies in order to achieve maximum benefit for the students and optimum utilization of teaching resources. Finally, it is recommended that employers facilitate in every possible way employee participation in programs of continuing engineering studies.*

# APPENDIX III

# SUBJECT MATTER CONTENT OF A BASIC ENGINEERING CURRICULUM

Following are some of the main ingredients suggested for a basic engineering curriculum. They have been chosen partly because they are thought to be basic to the understanding of future developments in engineering. The present graduates will reach their professional peak around the year 2000 and much of what they will need to know then will have to be learned in future years—hopefully with the aid of some of the tools provided by the curriculum.

### *Mathematics*

Replies to the Industry-Government Survey and from Institutional and Organizational Study Committees indicate that engineers of tomorrow must have a deeper understanding of mathematics, and better general ability to handle theory and techniques of analysis than did the pre-World War II engineers. However, concern is expressed in some of these reports that in the future the particular mathematical and scientific education of engineering students now being given may not prove to be applicable and that applied mathematics should receive greater stress.

The Industry-Government Survey (Ref. C-4) indicates (Table III-1) that practicing engineers strongly recommend traditional courses such as algebra, trigonometry, calculus, and analytical geometry, and as strongly suggest differential equations and vector analysis. Over two-thirds of the engineers recommended complex variables, despite the fact that less than one-third had occasion to use the subject during their own careers.

### *Computer Science*

The Institutional Study Committees report that it is essential for the engineer to have a knowledge of digital computers so that he may know what problems may best be solved on the computer and may be able, himself, to use the computer and direct others in doing so. Two-thirds held the view that: "The undergraduate engineer should acquire a basic understanding . . . of problem solving by both digital and analog computers" (Ref. C-5).

The need is stressed for educational experience which will enable the engineer to meet the rapid changes in technology and language that will be evolved rather than for knowledge of present techniques. Engineering already has been significantly affected by the use of digital computers, but even more profound and far-reaching changes are to be expected in the future.

Time-sharing systems may make it economically feasible for each engineer to have immediate access to the speed and storage capacity of a large machine. Development of graphical input and output devices will aid the engineer greatly in visualization of his problem, in performing manipulations, in arriving at a solution, and finally, in recording the solution in a usable form.

Engineering schools are in great need of funds to make these costly complex systems available to their students.

A committee of the ASEE in a 1965 report, "Computers in Engineering Education," concluded that while computers are being brought into engineering education, a push is needed. They recommended the formation of an ASEE task force to develop a single language, inexpensive instructional equipment, instructional programs for faculty, and courses and curricula for students as well as to help secure the necessary funds (Ref. III-1).

### *Physical Science*

The knowledge of natural laws and phenomena gained in courses in chemistry and physics is valuable to the engineer on its own account and is needed for understanding of the engineering sciences. In areas such as chemical engineering more emphasis may need to be placed on chemistry and chemical processes than on physics; hence, no attempt is made to specify a particular distribution of time between these physical sciences. Study of the biological sciences is essential in some curricula and is an asset to the general educational development of students, but should not replace work in physical science. Predictions noted in Part B of this report suggest that the engineer will need to know a great deal about biology in 1984 and more in 2000.

In the basic sciences, strong recommendations were made by practicing engineers for the inclusion of modern physics and physical and organic chemistry in future curricula despite the fact that many had no occasion to use such subjects themselves. (Both general physics and general chemistry were highly recommended and used.) From one-half to one-third favored such subjects as geology, biology, and astronomy despite low proportions indicating personal use of these subjects (Table III-1).

### *Engineering Science*

Strong support was given to engineering science subjects such as mechanics of solids and fluids, electric circuits, electronics, heat and mass transfer, properties of materials, and thermodynamics. Higher proportions of engineers recommended them for the future than indicated they had used their knowledge of these subjects in their careers (Table III-1).

The identification of certain subjects as "engineering science," which grew out of the Evaluation Study under Dean Grinter's direction (Ref. C-2) is reaffirmed in the current study.

Engineering science is coming to signify the study of physical phenomena utilized in artificial or man-made devices and systems as distinguished from basic science which is concerned with the phenomena of nature. The engineering sciences overlie the basic physical sciences and embrace the principles of engineering that are applicable to many areas. Like the basic sciences, the engineering sciences cut across most fields of engineering.

It is strongly suggested that an engineering student should be required to study most but not necessarily all of the following engineering sciences: (1) mechanics of solids and fluids; (2) electrical science including electric and magnetic fields, circuits, and electronics; (3) thermodynamics and statistical mechanics; (4) materials science; (5) information theory; (6) logic and computing devices; (7) systems analysis; (8) transfer and rate processes, including heat and mass transfer and some phases of fluid mechanics.

Various other modern subjects, such as those termed communication science, space science, environmental science and bio-engineering are possible areas for inclusion as engineering sciences for the future.

*Humanities and Social Studies*

It is recommended that action of the following kinds be taken in the days ahead by the ASEE, by individual institutions and faculty members:

(1) Strive to include the equivalent of one course per semester in history, literature, philosophy, political science, economics, psychology, and sociology or art, and provide for counseling of students in the choice of courses—this in accordance with the wide acceptancy by the engineering teaching profession of the parallel paths of the liberal and technological courses throughout the years of basic engineering education.

(2) Make a positive effort to implement the recommendations of the Humanistic and Social Science Research Project Report of 1956 which are as valid today as when they were written.

(3) Strive to increase the support, financial and otherwise, of departments and teachers in the humanities and social sciences.

(4) Encourage more teachers of science and engineering to become more liberally educated; to learn, for example, where the chapter on development of their own specialty fits into the general history of science and engineering and where that history, in turn, belongs on the shelf called "History of Civilization." Encourage teachers who have been so educated to share their insights and enthusiasms with their students.

(5) Increase the emphasis upon social sciences and humanities in the graduate curricula of engineering.

(6) Introduce more interdepartmental courses at the upper-class or graduate level in which interested and cooperative teachers from engineering and from such departments as economics and political science join in administering special projects such as city or regional planning or economic development, as is now being done at some institutions.

(7) Encourage experimentation with promising new approaches to the liberal education of the engineer—even expensive ones such as a year of study or employment in a foreign country as part of the coordinated plan to study; pre-professional education as in medicine and law; and experimentation with new techniques such as programmed learning.

*Communications*

Skills in communication—oral, written, graphical and mathematical—are gained from formal educational programs, from on-the-job experience and, perhaps most important, through off-the-job life-long learning. Every effort should be made to give the student experience in written and oral expression in all of his courses, for only through continuous practice throughout the college program can the needed improvement be realized. All engineering languages should be utilized—verbal (oral and written), pictorial and symbolic. Isolated freshman courses offering little more than minor extensions of high school courses seldom stimulate the student and are ineffective by comparison with the continuous attention recommended here.

English Composition and Speech ranked very high (Table III-1) among the recommended courses and among the subjects most extensively used by the responding engineers. This is confirmed by other information on engineers activities (Ref. III-2).

Engineering educators should support insistence on high standards of performance in writing, reading and speaking as a prerequisite for admission to engineering college. Furthermore, the engineering faculty must assume responsibility for constant attention in all courses to correcting and improving the written and oral presentations of their students.

Engineering graphics as a method of communication is a critical but controversial element of engineering education. Some engineering schools have eliminated the subject from the college curriculum. Instead they require it as a prerequisite for entrance or include it as a part of other courses such as design.

Engineering graphics was below the middle in rank among the subjects recommended for the future in engineering curricula but close to the upper quarter in rank of subjects used (Table III-1). Figure 11 of Information Document No. 7 (Ref. III-3) shows that reading and understanding of engineering drawings received the most numerous mention of any of the 15 activities engaged in during the previous month by all graduates. More than 60 percent of the bachelor's and master's engineers so reported. (The next in rank order of such listing was detailed design.) On the other hand, only about 12 percent of these engineers reported that they had engaged in detail drafting during the previous month.

TABLE III-1

FUTURE RECOMMENDATIONS, USE, AND CURRENT KNOWLEDGE OF SELECTED COLLEGE SUBJECTS

| SUBJECT | Recommended for Future | | Used During Past Month | | Used During Career | | Taken in College | | CURRENT KNOWLEDGE: Extensive | | CURRENT KNOWLEDGE: Extensive & General | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | RANK | % | RANK | % | RANK | % | RANK | % | RANK | % | RANK |
| Algebra | 99 | 01 | 62 | 02 | 98 | 01 | 100 | 01 | 44 | 01 | 100 | 01 |
| Physics (General) | 99 | 02 | 41 | 06 | 95 | 04 | 99 | 03 | 21 | 09 | 99 | 04 |
| English Composition | 99 | 03 | 78 | 01 | 98 | 02 | 97 | 07 | 26 | 04 | 99 | 03 |
| Trigonometry | 99 | 04 | 51 | 03 | 96 | 03 | 100 | 02 | 41 | 02 | 100 | 02 |
| Calculus | 97 | 05 | 23 | 18 | 81 | 12 | 99 | 04 | 24 | 05 | 92 | 11 |
| Speech | 96 | 06 | 51 | 04 | 92 | 05 | 77 | 22 | 15 | 17 | 94 | 07 |
| Mechanics of Solids | 95 | 07 | 28 | 13 | 83 | 09 | 88 | 13 | 22 | 07 | 89 | 15 |
| Chemistry (General) | 95 | 08 | 26 | 14 | 78 | 19 | 98 | 05 | 12 | 24 | 93 | 08 |
| Analytical Geometry | 95 | 09 | 19 | 25 | 82 | 11 | 98 | 06 | 17 | 13 | 96 | 05 |
| Electric Circuits | 94 | 10 | 33 | 09 | 82 | 10 | 91 | 10 | 21 | 08 | 90 | 12 |
| Strength of Materials | 94 | 11 | 32 | 10 | 87 | 08 | 94 | 08 | 24 | 06 | 94 | 06 |
| Engineering Design | 93 | 12 | 47 | 05 | 91 | 06 | 82 | 16 | 33 | 03 | 93 | 10 |
| Mechanics of Fluids | 92 | 13 | 26 | 15 | 79 | 14 | 84 | 15 | 19 | 10 | 86 | 17 |
| Properties of Materials | 92 | 14 | 35 | 07 | 88 | 07 | 81 | 17 | 17 | 12 | 90 | 13 |
| Thermodynamics | 91 | 15 | 19 | 26 | 72 | 21 | 90 | 11 | 15 | 19 | 86 | 18 |
| Statistics | 90 | 16 | 24 | 17 | 78 | 16 | 52 | 29 | 10 | 27 | 76 | 24 |
| Solid Geometry | 90 | 17 | 18 | 28 | 79 | 15 | 93 | 09 | 15 | 15 | 93 | 09 |
| Differential Equations | 89 | 18 | 16 | 30 | 61 | 26 | 85 | 14 | 15 | 19 | 77 | 23 |
| Engineering Economics | 89 | 19 | 32 | 11 | 77 | 18 | 58 | 25 | 15 | 17 | 82 | 20 |
| Economics | 89 | 20 | 34 | 08 | 78 | 17 | 80 | 19 | 09 | 28 | 89 | 14 |
| Electronics | 88 | 21 | 24 | 16 | 61 | 28 | 57 | 26 | 15 | 17 | 65 | 28 |
| Engineering Laboratory | 88 | 22 | 21 | 20 | 70 | 22 | 78 | 21 | 17 | 13 | 82 | 21 |
| Electric & Magnetic Fields | 87 | 23 | 20 | 24 | 63 | 24 | 80 | 18 | 14 | 21 | 79 | 22 |
| Modern Physics | 87 | 24 | 10 | 36 | 38 | 37 | 40 | 32 | 04 | 37 | 50 | 36 |
| Heat & Mass Transfer | 87 | 25 | 20 | 22 | 68 | 23 | 73 | 23 | 14 | 22 | 76 | 25 |
| Engineering Graphics | 86 | 26 | 28 | 12 | 80 | 13 | 78 | 20 | 18 | 11 | 84 | 19 |
| Descriptive Geometry | 84 | 27 | 13 | 33 | 73 | 20 | 90 | 12 | 13 | 23 | 88 | 16 |
| Vector Analysis | 84 | 28 | 11 | 35 | 62 | 25 | 67 | 24 | 11 | 25 | 71 | 26 |
| Engineering Systems | 83 | 29 | 18 | 27 | 61 | 27 | 36 | 35 | 11 | 26 | 66 | 27 |
| Industrial Management | 78 | 30 | 20 | 23 | 55 | 30 | 29 | 38 | 08 | 29 | 63 | 31 |
| Psychology | 70 | 31 | 22 | 19 | 54 | 31 | 41 | 31 | 02 | 38 | 63 | 30 |
| Industrial Relations | 70 | 31 | 16 | 29 | 53 | 32 | 24 | 41 | 05 | 35 | 58 | 32 |
| Physical Chemistry | 69 | 33 | 15 | 32 | 46 | 33 | 51 | 30 | 07 | 30 | 52 | 33 |
| Complex Variables | 69 | 33 | 06 | 40 | 33 | 39 | 39 | 33 | 07 | 30 | 41 | 42 |
| Law | 68 | 35 | 09 | 37 | 44 | 34 | 35 | 36 | 01 | 41 | 50 | 38 |
| Accounting | 66 | 36 | 21 | 21 | 57 | 29 | 38 | 34 | 05 | 34 | 64 | 29 |
| Organic Chemistry | 64 | 37 | 15 | 31 | 43 | 35 | 53 | 28 | 06 | 33 | 52 | 34 |
| Foreign Language | 64 | 38 | 07 | 38 | 37 | 38 | 56 | 27 | 06 | 32 | 51 | 35 |
| Marketing | 61 | 39 | 12 | 34 | 40 | 36 | 16 | 43 | 04 | 36 | 44 | 39 |
| Political Science | 52 | 40 | 04 | 42 | 24 | 42 | 27 | 39 | 02 | 40 | 50 | 37 |
| Sociology | 46 | 41 | 05 | 41 | 25 | 41 | 21 | 42 | 01 | 42 | 42 | 40 |
| Geology | 44 | 42 | 06 | 39 | 30 | 40 | 30 | 37 | 02 | 38 | 41 | 41 |
| Biology | 34 | 43 | 01 | 44 | 14 | 43 | 26 | 40 | 01 | 43 | 37 | 43 |
| Astronomy | 31 | 44 | 02 | 43 | 13 | 44 | 14 | 44 | 01 | 43 | 31 | 44 |

The engineer should be able to visualize spatial relations and to supply graphical techniques for the analysis and synthesis of complex relationships. Yet, teachers of engineering drawing and engineering graphics have often seemed separated from the main stream of thought and developments in engineering education. Recently, however, interest in this important area has been renewed as a result of the expanded use of the computer as a graphical tool applicable to problems in space as well as a device for storing and retrieving information heretofore available only in the form of engineering drawings (Refs. III-4, III-5, III-6).

Hopefully, these developments will stimulate and attract the vigorous and creative teachers needed in this important field.

*Synthesis, Analysis, Design of Systems and of Their Components*

The importance of creative design throughout undergraduate and graduate programs deserves the immediate attention of engineering educators. They must develop greatly improved programs which will give the student an opportunity to experience the thrills of invention, the excitement of original and imaginative thought in his chosen field.

In the last year of his basic engineering program the student might undertake a fairly sophisticated engineering system design project as a capstone of the program. This pedagogical capstone should integrate the learning experiences of the entire curriculum and bring to bear the knowledge and tools the student has acquired. Creativity, innovation and judgment should be encouraged. The student should gain experience in the use of optimization techniques and decision theory which require consideration of performance, scheduling, reliability and cost.

Analysis and synthesis of complex engineering systems, dealing with problems as a whole, must have greater attention and emphasis.

A high percentage of engineering graduates reported using their knowledge of design—especially bachelor's graduates and those engaged in management and design functions (Ref. III-7).

*Experimental Engineering*

Experimental engineering experiences are highly recommended because of the following considerations:

(1) Techniques can be introduced which lead to understanding of precision in measuring with instruments.

(2) Laboratory work leads to evaluation of performance of design and sometimes to the discovery of results not anticipated by theory.

(3) Laboratory work gives the student a "feeling" for the actual physical situation.

(4) Laboratory work, like engineering analysis, can deal with a system from conception to final evaluation, thus furnishing a view of an entire problem.

(5) The laboratory exercise can demonstrate principles discussed in class as well as provide additional knowledge.

(6) In the laboratory the student learns, often for the first time, that actual values are different from nominal values. He discovers the importance of variability of rated capacities as well as of measurements and of second order effects often disregarded in theories.

Eighty percent of the reports from Institutional Committees held the view that "A good program must include laboratory work" (Ref. III-8).

*Engineering Ethics—Inculcation of Professional Attitudes*

This is regarded less as a subject of instruction than as a teaching responsibility to be widely shared by the faculty and the professional societies. Particular courses or lecture series should not be depended upon exclusively to perform this vital service. Seventy-three percent of the Institutional Reports held this view: "(engineering ethics) . . . should be woven into other courses at the appropriate times" (Ref. C-5). Yet, formal provisions may well be made in the curriculum and in the program of the student societies to make sure that this important matter is not overlooked. Among these provisions are the following: (a) instruction in the history of engineering with strong emphasis on its service to society; (b) instruction in ethics and in the legal aspects of engineering and consideration of the issue of divided loyalties (Ref. III-9); (c) instruction in the organizational framework of engineering and of the sector of society in which the engineer performs.

# APPENDIX IV

# DIVERSITY OF EDUCATIONAL INSTITUTIONS

### *Larger Engineering Schools*

More than 89 percent of engineering graduates from accredited curricula come from institutions which award annually more than 100 bachelor's degrees. But they constitute only about two-thirds of the total number of schools with accredited curricula (Ref. IV-1). Many larger engineering schools are in Land Grant institutions or other state universities. Some of the privately endowed institutions of technology and several of the metropolitan universities have sizable numbers of graduates, but the latter, whose enrollments are often very large because they include evening-class students, account for only about five percent of the total number of bachelor's degrees awarded from accredited engineering curricula (Ref. IV-2).

The curricular offerings at the larger institutions tend to be numerous and varied and may be expected to include several varieties of the basic program recommended in this report.

### *Small Engineering Colleges*

The small engineering colleges, on the other hand, should not be urged to provide many optional curricula because many of them simply cannot successfully teach more than a moderate number of subjects. The wisest course for most to pursue is to concentrate on a very few engineering curricula, perhaps on the single one that it is best qualified to teach and that will meet the needs of the majority of its student clientele. The concept of flexibility and diversity should be interpreted in this instance to allow, indeed to encourage, each institution to find its proper individual role, offering perhaps a particular engineering curriculum, such as civil engineering, needed to round out the educational offerings of the region in which it is located or to foster the special talents of a highly selected group of students from a wider area. In any case it should strive to fit itself to perform its adopted role as well and efficiently as it can.

In a sense this policy would expand the flexibility of choice of curricula (or curriculum) by the institution but narrow the range or diversity of the choice of curriculum by the student in a given institution. But if the curricula of the numerous separate institutions in a given region are appropriately varied, and if the student has the option of choice of institutions, he may find the particular curriculum that meets his special requirements. This, after all, is the main goal of the recommended flexibility.

### *Community Colleges*

The community college whose clientele includes students of many differing interests and aptitudes and correspondingly different career plans should be encouraged to adopt a different policy from that of the small engineering college just considered. Nevertheless, the need is urgent for concentration of effort on the limited number of courses that can successfully be presented at a given school. In this case those few fundamental courses should be taught that are common to many curricula which are preparatory for widely different careers. The student who successfully completes such courses should be encouraged to transfer to other colleges for the more advanced specialized studies in particular fields not offered at this institution. Such a policy would not necessarily preclude the offering of a *limited* number of specialized courses of particular interest to students of the region.

This concept of flexibility in establishing engineering curricula to fit current patterns of education and employment of engineers also implies a flexibility in the amount of education engineers receive as well as in the type of education. Thus, the growing need for engineers with advanced degrees must be provided for in the years ahead. However, providing for this need does not mean that every engineering school should offer a curriculum leading to a master's degree. Some schools will (or probably should) continue to maintain only the established programs leading to a baccalaureate degree.

### *Role of Institutions for Technician Training*

There is a growing demand for supporting technical personnel for engineers and scientists who will be of immediate service to industry—as soon as hired.

Over one-third of the organizations covered by the Industry-Government Survey indicate that the present supply of technicians is inadequate. Over three-fourths projected a need for increasing numbers in the future—as many as one-fifth indicating a doubling of technician needs (Ref. IV-3). A National Science Foundation study indicated that by 1970 there will be a need for approximately 1.5 million engineers (Ref. IV-4). If, as some have suggested, the economy needs about two to four technicians for each engineer or scientist (Ref. IV-5), then the production of technicians is falling far short of the need. For example, in 1964 there were 43,000 engineering degrees awarded and only 14,471 associate degrees in two-year technician programs.

But enrollment is expanding. Patrick's report on 177 institutions offering technician programs shows an increase of enrollment from 57,589 in 1963 to 65,731 in 1964—some 14 percent (Ref. IV-6).

Little is known about the production of technicians who do not obtain an associate degree. They are often trained in industry, and comprise an important sector of the supporting personnel for engineers.

A recent study indicates that there are currently 73 institutions offering four-year technician programs (Ref. IV-7). Most of these programs are very new, appearing after 1950.

# APPENDIX V

# BACHELOR'S DEGREES IN ENGINEERING

**(One-Year Period Ending June 1966)**

(Institutions With At Least One ECPD-Accredited Curriculum)

| No. | Percent of Inst. | Institution | No. of Degrees | Percent of Degrees |
|---|---|---|---|---|
| 1 | 0.6 | Purdue U. | 945 | 3.0 |
| 2 | 1.1 | U. of Illinois | 754 | 5.3 |
| 3 | 1.7 | Georgia Inst. of Tech. | 623 | 7.3 |
| 4 | 2.2 | U. of Michigan | 615 | 9.2 |
| 5 | 2.8 | Newark Coll. | 603 | 11.1 |
| 6 | 3.4 | Pennsylvania St. U. | 578 | 13.0 |
| 7 | 3.9 | No. Carolina St. U. | 534 | 14.6 |
| 8 | 4.4 | U. of Missouri (Rolla) | 532 | 16.3 |
| 9 | 5.0 | U. of Calif. (Berkeley) | 509 | 17.9 |
| 10 | 5.6 | Virginia Poly. Inst. | 488 | 19.4 |
| 11 | 6.1 | U. of Minnesota | 479 | 21.0 |
| 12 | 6.7 | Drexel Inst. Tech. | 459 | 22.4 |
| 13 | 7.2 | CUNY City Coll. | 451 | 23.8 |
| 14 | 7.8 | U. of Wisconsin | 429 | 25.2 |
| 15 | 8.3 | U. of Washington | 418 | 26.4 |
| 16 | 8.9 | Auburn U. | 416 | 27.8 |
| 17 | 9.4 | Northeastern U. | 416 | 29.0 |
| 18 | 10.1 | Mass. Inst. of Tech. | 414 | 30.4 |
| 19 | 10.6 | U. of Florida | 396 | 31.6 |
| 20 | 11.1 | Rensselaer Poly. Inst. | 389 | 32.9 |
| 21 | 11.7 | Cornell U. | 385 | 34.0 |
| 22 | 12.2 | Iowa St. U. | 372 | 35.2 |
| 23 | 12.8 | Michigan Tech. U. | 370 | 36.4 |
| 24 | 13.4 | U. of Texas | 366 | 37.6 |
| 25 | 14.0 | Ohio St. U. | 361 | 38.7 |
| 26 | 14.5 | U. of Tennessee | 328 | 39.7 |
| 27 | 15.1 | Texas A and M U. | 327 | 40.8 |
| 28 | 15.6 | Illinois Inst. of Tech. | 324 | 41.8 |
| 29 | 16.2 | Poly. Inst. of Brooklyn | 316 | 42.8 |
| 30 | 16.8 | U. of Maryland | 297 | 43.7 |
| 31 | 17.3 | U. of Cincinnati | 285 | 44.6 |
| 32 | 17.9 | U. of Notre Dame | 266 | 45.4 |
| 33 | 18.4 | Oklahoma St. U. | 260 | 46.2 |
| 34 | 19.0 | Lehigh U. | 257 | 47.0 |
| 35 | 19.6 | U. of Colorado | 255 | 47.9 |
| 36 | 20.1 | Manhattan U. | 249 | 48.7 |
| 37 | 20.7 | U. of Pittsburgh | 247 | 49.4 |
| 38 | 21.2 | UCLA | 247 | 50.2 |
| 39 | 21.8 | Michigan St. U. | 237 | 51.0 |
| 40 | 22.3 | U. of Detroit | 234 | 51.7 |
| 41 | 22.9 | Carnegie Inst. of Tech. | 227 | 52.4 |
| 42 | 23.4 | U.S. Air Force Academy | 223 | 53.1 |
| 43 | 24.0 | Worcester Poly. Inst. | 221 | 53.8 |
| 44 | 24.6 | U. of Nebraska | 220 | 54.4 |
| 45 | 25.1 | Kansas St. U. | 216 | 55.1 |
| 46 | 25.7 | Marquette U. | 216 | 55.9 |
| 47 | 26.2 | U. of Missouri (Columbia) | 209 | 56.5 |
| 48 | 26.8 | Louisiana St. U. | 205 | 57.1 |
| 49 | 27.3 | Case Inst. of Tech. | 204 | 57.8 |
| 50 | 27.9 | Johns Hopkins U. | 204 | 58.4 |
| 51 | 28.4 | Mississippi St. U. | 204 | 59.0 |
| 52 | 29.0 | New York U. | 201 | 59.7 |
| 53 | 29.6 | U. of Oklahoma | 200 | 60.3 |
| 54 | 30.1 | Oregon St. U. | 200 | 61.0 |
| 55 | 30.7 | U. of Puerto Rico | 200 | 61.6 |
| 56 | 31.2 | St. Louis U. | 199 | 62.2 |
| 57 | 31.8 | San Jose St. Coll. | 198 | 62.8 |
| 58 | 32.4 | Clarkson Coll. of Tech. | 195 | 63.4 |
| 59 | 33.0 | U. of Alabama | 194 | 64.0 |
| 60 | 33.5 | New Mexico St. U. | 194 | 64.7 |
| 61 | 34.0 | U. of Arizona | 191 | 65.2 |
| 62 | 34.6 | Villanova U. | 191 | 65.9 |
| 63 | 35.1 | Texas Tech. Coll. | 189 | 66.4 |
| 64 | 35.8 | Colorado Sch. of Mines | 187 | 67.0 |
| 65 | 36.3 | Clemson U. | 186 | 67.7 |
| 66 | 36.9 | U. of Kansas | 181 | 68.2 |
| 67 | 37.4 | U. of Utah | 180 | 68.8 |
| 68 | 38.0 | Washington St. U. | 179 | 69.3 |
| 69 | 38.5 | U. of Arkansas | 175 | 69.9 |
| 70 | 39.1 | U. of Kentucky | 174 | 70.4 |
| 71 | 39.7 | Stevens Inst. of Tech. | 174 | 71.1 |
| 72 | 40.2 | West Virginia U. | 169 | 71.5 |
| 73 | 40.8 | No. Dakota St. U. | 161 | 72.0 |
| 74 | 41.3 | U. of Dayton | 157 | 72.5 |
| 75 | 41.9 | Fairleigh Dickinson U. | 154 | 73.0 |
| 76 | 42.5 | SUNY at Buffalo | 152 | 73.4 |
| 77 | 43.0 | Wayne St. U. | 149 | 74.0 |
| 78 | 43.6 | U. of Wyoming | 149 | 74.4 |
| 79 | 44.1 | Cleveland St. U. | 147 | 74.9 |
| 80 | 44.7 | Stanford U. | 147 | 75.3 |
| 81 | 45.2 | U. of Maine | 145 | 75.8 |
| 82 | 45.8 | Tufts U. | 144 | 76.2 |
| 83 | 46.4 | Lowell Tech. Inst. | 140 | 76.7 |
| 84 | 46.9 | Ohio U. | 140 | 77.1 |
| 85 | 47.4 | Northwestern U. | 137 | 77.6 |
| 86 | 48.0 | U. of Houston | 134 | 78.0 |
| 87 | 48.6 | Arizona St. U. | 132 | 78.4 |
| 88 | 49.1 | So. Dakota Sch. of M. and T. | 132 | 78.8 |
| 89 | 49.7 | Calif. St. Coll. at L.A. | 131 | 79.2 |
| 90 | 50.3 | Cooper Union | 131 | 79.6 |
| 91 | 50.8 | Montana St. U. | 131 | 80.0 |
| 92 | 51.4 | U. of Massachusetts | 130 | 80.4 |
| 93 | 52.0 | U. of Idaho | 129 | 80.9 |
| 94 | 52.5 | U. of Southern Calif. | 126 | 81.2 |
| 95 | 53.0 | Calif. St. Coll. at Long Beach | 125 | 81.7 |
| 96 | 53.6 | U. of New Mexico | 124 | 82.0 |
| 97 | 54.1 | Tennessee Tech. U. | 123 | 82.4 |
| 98 | 54.7 | Vanderbilt U. | 123 | 82.8 |
| 99 | 55.3 | Rutgers St. U. | 122 | 83.2 |
| 100 | 55.9 | Arlington St. Coll. | 120 | 83.6 |
| 101 | 56.4 | Lamar St. Coll. | 117 | 84.0 |
| 102 | 57.0 | So. Dakota St. U. | 117 | 84.3 |
| 103 | 57.5 | Columbia U. | 116 | 84.7 |
| 104 | 58.1 | Louisiana Poly. Inst. | 116 | 85.0 |
| 105 | 58.7 | U. of Rhode Island | 114 | 85.4 |
| 106 | 59.2 | U. of Hawaii | 113 | 85.8 |
| 107 | 59.8 | Washington U. | 112 | 86.1 |
| 108 | 60.3 | Youngstown U. | 112 | 86.4 |
| 109 | 60.9 | U. of Connecticut | 110 | 86.8 |
| 110 | 61.4 | U. of Toledo | 109 | 87.1 |
| 111 | 62.0 | Colorado St. U. | 108 | 87.5 |
| 112 | 62.6 | U. of Iowa | 107 | 87.8 |
| 113 | 63.1 | Syracuse U. | 106 | 88.1 |
| 114 | 63.7 | Lafayette Coll. | 105 | 88.5 |
| 115 | 64.2 | U. of Louisville | 105 | 88.8 |
| 116 | 64.8 | Rose Poly. Inst. | 101 | 89.1 |
| 117 | 65.3 | U.S. Naval Postgraduate Sch. | 100 | 89.4 |
| 118 | 65.9 | Princeton U. | 95 | 89.8 |
| 119 | 66.4 | U. of Virginia | 92 | 90.0 |
| 120 | 67.0 | Utah St. U. | 92 | 90.3 |
| 121 | 67.6 | U. of Miami | 91 | 90.6 |
| 122 | 68.1 | Rice U. | 90 | 90.9 |
| 123 | 68.7 | U. of Delaware | 90 | 91.1 |
| 124 | 69.2 | U. of New Hampshire | 87 | 91.4 |
| 125 | 69.8 | Southern Methodist U. | 86 | 91.7 |
| 126 | 70.3 | Brigham Young U. | 85 | 92.0 |
| 127 | 70.9 | Bucknell U. | 83 | 92.2 |
| 128 | 71.5 | Virginia Military Inst. | 82 | 92.5 |
| 129 | 72.0 | U. of Pennsylvania | 81 | 92.8 |
| 130 | 72.6 | Duke U. | 78 | 93.0 |
| 131 | 73.1 | Howard U. | 73 | 93.2 |
| 132 | 73.7 | Bradley U. | 72 | 93.4 |
| 133 | 74.3 | San Diego St. Coll. | 70 | 93.7 |
| 134 | 74.9 | U. of North Dakota | 70 | 93.9 |
| 135 | 75.4 | Pratt Inst. | 68 | 94.1 |
| 136 | 76.0 | U. of Calif. (Davis) | 68 | 94.3 |
| 137 | 76.5 | U. of Southwestern La. | 68 | 94.6 |
| 138 | 77.1 | Valparaiso U. | 67 | 94.8 |
| 139 | 77.7 | George Washington U. | 65 | 95.0 |
| 140 | 78.2 | PMC Colleges | 65 | 95.1 |
| 141 | 78.8 | U. of Texas at El Paso | 61 | 95.3 |
| 142 | 79.3 | San Fernando Valley St. Coll. | 60 | 95.6 |
| 143 | 79.9 | SUNY Coll. of Ceramics | 56 | 95.7 |
| 144 | 80.4 | U. of Santa Clara | 56 | 95.9 |
| 145 | 81.0 | Brown U. | 54 | 96.0 |
| 146 | 81.6 | U. of So. Carolina | 53 | 96.2 |
| 147 | 82.1 | Dartmouth Coll. | 52 | 96.4 |
| 148 | 82.7 | Union Coll. | 52 | 96.6 |
| 149 | 83.2 | U. of Bridgeport | 52 | 96.7 |
| 150 | 83.8 | Sacramento St. Coll. | 51 | 96.9 |
| 151 | 84.3 | U. of Tulsa | 51 | 97.0 |
| 152 | 84.9 | Wichita St. U. | 51 | 97.2 |
| 153 | 85.4 | U. of Mississippi | 50 | 97.3 |
| 154 | 86.0 | Air Force Inst. of Tech. | 49 | 97.5 |
| 155 | 86.6 | Norwich U. | 49 | 97.7 |
| 156 | 87.1 | U. of Akron | 49 | 97.8 |
| 157 | 87.7 | Calif. Inst. of Tech. | 48 | 98.0 |
| 158 | 88.2 | Catholic U. of America | 47 | 98.1 |
| 159 | 88.8 | Citadel Military Coll. | 46 | 98.2 |
| 160 | 89.3 | U. of Nevada | 45 | 98.4 |
| 161 | 89.9 | U. of Vermont | 44 | 98.6 |
| 162 | 90.5 | Fresno St. Coll. | 41 | 98.7 |
| 163 | 91.0 | Seattle U. | 40 | 98.8 |
| 164 | 91.6 | Tulane U. | 40 | 99.0 |
| 165 | 92.1 | Ohio Northern U. | 33 | 99.0 |
| 166 | 92.7 | Montana Coll. of M. S. and T. | 31 | 99.1 |
| 167 | 93.3 | U. of Denver | 31 | 99.2 |
| 168 | 93.9 | U. of Rochester | 31 | 99.3 |
| 169 | 94.4 | Gannon Coll. | 26 | 99.4 |
| 170 | 95.0 | Harvard U. | 24 | 99.5 |
| 171 | 95.5 | Merrimack Coll. | 24 | 99.6 |
| 172 | 96.0 | Tuskegee Inst. | 23 | 99.7 |
| 173 | 96.6 | U. of Alaska | 22 | 99.7 |
| 174 | 97.2 | SUNY at Stony Brook | 20 | 99.8 |
| 175 | 97.8 | U. of Georgia | 19 | 99.8 |
| 176 | 98.3 | Swarthmore Coll. | 18 | 99.9 |
| 177 | 98.9 | Webb Inst. of Nav. Arch. | 16 | 100.0 |
| 178 | 99.4 | Harvey Mudd Coll. | 10 | 100.0 |
| 179 | 100.0 | Antioch Coll. | 5 | 100.0 |
| | | Total | 31,788 | |

# APPENDIX VI

# MASTER'S DEGREES IN ENGINEERING

**(One-Year Period Ending June 1966)**

(Institutions With At Least One Bachelor's ECPD-Accredited Curriculum)

| No. | Percent of Inst. | Institution | No. of Degrees | Percent of Degrees |
|---|---|---|---|---|
| 1 | 0.6 | Mass. Inst. of Tech. | 570 | 4.3 |
| 2 | 1.2 | U. of Southern Calif. | 509 | 8.2 |
| 3 | 1.9 | Stanford U. | 467 | 11.7 |
| 4 | 2.6 | U. of Calif. (Berkeley) | 466 | 15.2 |
| 5 | 3.2 | Purdue U. | 437 | 18.5 |
| 6 | 3.8 | New York U. | 420 | 21.7 |
| 7 | 4.4 | U. of Michigan | 375 | 24.5 |
| 8 | 5.1 | Cornell U. | 336 | 27.0 |
| 9 | 5.8 | U. of Illinois | 309 | 29.4 |
| 10 | 6.4 | Northeastern U. | 295 | 31.6 |
| 11 | 7.0 | Poly. Inst. Brooklyn | 263 | 33.6 |
| 12 | 7.7 | UCLA | 243 | 35.5 |
| 13 | 8.3 | Air Force Inst. of Tech. | 240 | 37.3 |
| 14 | 9.0 | Columbia U. | 225 | 39.0 |
| 15 | 9.6 | Oklahoma St. U. | 220 | 40.6 |
| 16 | 10.2 | U. of Wisconsin | 208 | 42.2 |
| 17 | 10.9 | Ohio St. U. | 185 | 43.6 |
| 18 | 11.5 | Newark Coll. | 177 | 45.0 |
| 19 | 12.1 | Drexel Inst. of Tech. | 175 | 46.3 |
| 20 | 12.8 | U. of Washington | 171 | 47.6 |
| 21 | 13.4 | Pennsylvania St. U. | 170 | 48.8 |
| 22 | 14.1 | U. of Missouri (Rolla) | 168 | 50.1 |
| 23 | 14.7 | U. of Pennsylvania | 160 | 51.3 |
| 24 | 15.3 | U. of Minnesota | 155 | 52.5 |
| 25 | 16.0 | U. of Florida | 149 | 53.6 |
| 26 | 16.7 | Georgia Inst. of Tech. | 146 | 54.7 |
| 27 | 17.3 | Stevens Inst. of Tech. | 141 | 55.8 |
| 28 | 17.9 | U. of Connecticut | 136 | 56.8 |
| 29 | 18.6 | Illinois Inst. of Tech. | 131 | 57.8 |
| 30 | 19.2 | Southern Methodist U. | 130 | 58.8 |
| 31 | 19.9 | Rensselaer Poly. Inst. | 124 | 59.7 |
| 32 | 20.5 | Carnegie Inst. of Tech. | 123 | 60.7 |
| 33 | 21.1 | U. of Texas | 120 | 61.6 |
| 34 | 21.8 | U. of Tennessee | 117 | 62.5 |
| 35 | 22.4 | Case Inst. of Tech. | 110 | 63.3 |
| 36 | 23.0 | Syracuse U. | 106 | 64.1 |
| 37 | 23.7 | Northwestern U. | 105 | 64.9 |
| 38 | 24.3 | U. of Missouri (Columbia) | 104 | 65.7 |
| 39 | 25.0 | Princeton U. | 102 | 66.4 |
| 40 | 25.6 | U. of Colorado | 101 | 67.2 |
| 41 | 26.2 | Texas A and M U. | 101 | 68.0 |
| 42 | 26.9 | CUNY City Coll. | 100 | 68.7 |
| 43 | 27.6 | No. Carolina St. U. | 100 | 69.5 |
| 44 | 28.2 | Calif. Inst. Tech. | 97 | 70.2 |
| 45 | 28.8 | Iowa St. U. | 97 | 71.0 |
| 46 | 29.4 | George Washington U. | 94 | 71.7 |
| 47 | 30.1 | U. of Arizona | 93 | 72.4 |
| 48 | 30.8 | U. of Oklahoma | 93 | 73.1 |
| 49 | 31.4 | U. of New Mexico | 89 | 73.7 |
| 50 | 32.0 | Kansas St. U. | 88 | 74.4 |
| 51 | 32.7 | Virginia Poly. Inst. | 88 | 75.1 |
| 52 | 33.3 | U. of Pittsburgh | 86 | 75.7 |
| 53 | 34.0 | Wayne St. U. | 84 | 76.4 |
| 54 | 34.6 | Lehigh U. | 78 | 77.0 |
| 55 | 35.2 | Arizona St. U. | 76 | 77.5 |
| 56 | 35.9 | San Jose St. Coll. | 76 | 78.1 |
| 57 | 36.5 | U. of Kansas | 76 | 78.7 |
| 58 | 37.1 | U. of Santa Clara | 76 | 79.3 |
| 59 | 37.8 | West Virginia U. | 74 | 79.8 |
| 60 | 38.4 | Michigan St. U. | 69 | 80.3 |
| 61 | 39.1 | U.S. Naval Postgraduate Sch. | 66 | 80.8 |
| 62 | 39.7 | U. of Notre Dame | 66 | 81.3 |
| 63 | 40.3 | Louisiana St. U. | 64 | 81.8 |
| 64 | 41.0 | Washington U. | 64 | 82.3 |
| 65 | 41.7 | U. of Cincinnati | 62 | 82.8 |
| 66 | 42.3 | U. of Iowa | 58 | 83.2 |
| 67 | 42.9 | U. of Alabama | 56 | 83.6 |
| 68 | 43.6 | U. of Kentucky | 53 | 84.0 |
| 69 | 44.2 | Harvard U. | 52 | 84.4 |
| 70 | 44.9 | Utah St. U. | 51 | 84.8 |
| 71 | 45.5 | Catholic U. of America | 50 | 85.2 |
| 72 | 46.1 | U. of Nebraska | 50 | 85.6 |
| 73 | 46.8 | Texas Tech. Coll. | 49 | 85.9 |
| 74 | 47.4 | U. of Maryland | 48 | 86.3 |
| 75 | 48.0 | Colorado St. U. | 46 | 86.6 |
| 76 | 48.7 | U. of Virginia | 45 | 87.0 |
| 77 | 49.3 | Auburn U. | 44 | 87.3 |
| 78 | 50.0 | SUNY at Buffalo | 44 | 87.7 |
| 79 | 50.6 | U. of Delaware | 43 | 88.0 |
| 80 | 51.2 | U. of Maine | 43 | 88.3 |
| 81 | 51.9 | U. of Massachusetts | 43 | 88.6 |
| 82 | 52.6 | U. of Utah | 43 | 89.0 |
| 83 | 53.2 | U. of Rhode Island | 42 | 89.3 |
| 84 | 53.8 | Oregon St. U. | 41 | 89.6 |
| 85 | 54.4 | Johns Hopkins U. | 40 | 89.9 |
| 86 | 55.1 | U. of Toledo | 40 | 90.2 |
| 87 | 55.8 | Mississippi St. U. | 39 | 90.5 |
| 88 | 56.4 | Rice U. | 39 | 90.8 |
| 89 | 57.0 | Clemson U. | 37 | 91.0 |
| 90 | 57.7 | U. of Idaho | 37 | 91.3 |
| 91 | 58.3 | Worcester Poly. Inst. | 36 | 91.6 |
| 92 | 59.0 | Colorado Sch. of Mines | 34 | 91.9 |
| 93 | 59.6 | No. Dakota St. U. | 34 | 92.1 |
| 94 | 60.2 | U. of Rochester | 34 | 92.4 |
| 95 | 60.9 | U. of Wyoming | 34 | 92.6 |
| 96 | 61.5 | U. of Arkansas | 33 | 92.9 |
| 97 | 62.1 | Rutgers St. U. | 32 | 93.1 |
| 98 | 62.8 | Washington St. U. | 32 | 93.4 |
| 99 | 63.4 | Bradley U. | 31 | 93.6 |
| 100 | 64.1 | Louisiana Poly. Inst. | 31 | 93.8 |
| 101 | 64.7 | Montana St. U. | 31 | 94.0 |
| 102 | 65.3 | New Mexico St. U. | 31 | 94.3 |
| 103 | 66.0 | Villanova U. | 31 | 94.5 |
| 104 | 66.7 | San Diego St. Coll. | 30 | 94.8 |
| 105 | 67.3 | U. of Calif. (Davis) | 30 | 95.0 |
| 106 | 67.9 | Clarkson Coll. | 27 | 95.2 |
| 107 | 68.6 | Brigham Young U. | 26 | 95.4 |
| 108 | 69.2 | Brown U. | 26 | 95.6 |
| 109 | 69.9 | Michigan Tech. U. | 26 | 95.8 |
| 110 | 70.5 | Union Coll. | 26 | 96.0 |
| 111 | 71.1 | Houston U. | 23 | 96.2 |
| 112 | 71.8 | Tulane U. | 23 | 96.3 |
| 113 | 72.4 | Tufts U. | 22 | 96.5 |
| 114 | 73.0 | U. of Akron | 21 | 96.7 |
| 115 | 73.7 | U. of Bridgeport | 20 | 96.8 |
| 116 | 74.3 | U. of Nevada | 20 | 97.0 |
| 117 | 75.0 | Vanderbilt U. | 20 | 97.1 |
| 118 | 75.6 | St. Louis U. | 19 | 97.3 |
| 119 | 76.2 | U. of Detroit | 19 | 97.4 |
| 120 | 76.9 | Duke U. | 18 | 97.5 |
| 121 | 77.6 | Lowell Tech. Inst. | 17 | 97.7 |
| 122 | 78.2 | U. of Alaska | 17 | 97.8 |
| 123 | 78.8 | U. of Tulsa | 17 | 97.9 |
| 124 | 79.4 | So. Dakota St. U. | 16 | 98.0 |
| 125 | 80.1 | U. of No. Dakota | 16 | 98.2 |
| 126 | 80.8 | So. Dakota Sch. of M. and T. | 15 | 98.3 |
| 127 | 81.4 | U. of New Hampshire | 15 | 98.4 |
| 128 | 82.0 | U. of Denver | 14 | 98.5 |
| 129 | 82.7 | U. of Hawaii | 14 | 98.6 |
| 130 | 83.3 | Manhattan Coll. | 12 | 98.7 |
| 131 | 84.0 | Ohio U. | 12 | 98.8 |
| 132 | 84.6 | Bucknell U. | 11 | 98.9 |
| 133 | 85.2 | Dartmouth Coll. | 10 | 98.9 |
| 134 | 85.9 | Marquette U. | 10 | 99.0 |
| 135 | 86.5 | Montana Coll. | 10 | 99.1 |
| 136 | 87.1 | Wichita St. U. | 10 | 99.2 |
| 137 | 87.8 | Seattle U. | 9 | 99.2 |
| 138 | 88.4 | Tuskegee Inst. | 9 | 99.3 |
| 139 | 89.1 | SUNY at Stony Brook | 8 | 99.4 |
| 140 | 89.7 | U. of Dayton | 8 | 99.4 |
| 141 | 90.3 | U. of Miami | 8 | 99.5 |
| 142 | 91.0 | U. of Mississippi | 8 | 99.5 |
| 143 | 91.7 | U. of So. Carolina | 8 | 99.6 |
| 144 | 92.3 | Lamar St. Coll. of Tech. | 7 | 99.7 |
| 145 | 92.9 | SUNY Coll. of Ceramics | 6 | 99.7 |
| 146 | 93.6 | U. of No. Carolina | 6 | 99.8 |
| 147 | 94.2 | U. of Louisville | 5 | 99.8 |
| 148 | 94.9 | Webb Inst. of Nav. Arch. | 5 | 99.8 |
| 149 | 95.5 | U. of Georgia | 4 | 99.8 |
| 150 | 96.1 | Calif. St. Coll. (Long Beach) | 3 | 99.9 |
| 151 | 96.8 | Rose Poly. Inst. | 3 | 99.9 |
| 152 | 97.4 | Sacramento St. Coll. | 3 | 99.9 |
| 153 | 98.0 | U. of Puerto Rico | 3 | 99.9 |
| 154 | 98.7 | U. of Vermont | 3 | 100.0 |
| 155 | 99.3 | Pratt Inst. | 2 | 100.0 |
| 156 | 100.0 | Tennessee Tech. U. | 2 | 100.0 |
| | | Total | 13,225 | |

# APPENDIX VII

# ENGINEER DEGREES

**(One-Year Period Ending June 1966)**

(Institutions With At Least One Bachelor's ECPD-Accredited Curriculum)

| No. | Percent of Inst. | Institution | No. of Degrees | Percent of Degrees |
|---|---|---|---|---|
| 1 | 12.5 | Mass. Inst. of Tech. | 126 | 55.0 |
| 2 | 25.0 | Stanford U. | 41 | 72.9 |
| 3 | 37.5 | Columbia U. | 36 | 88.6 |
| 4 | 50.0 | U. of Michigan | 10 | 93.0 |
| 5 | 62.5 | Calif. Inst. of Tech. | 8 | 96.5 |
| 6 | 75.0 | U.S. Naval Postgraduate Sch. | 6 | 99.1 |
| 7 | 87.5 | U. of Minnesota | 1 | 99.6 |
| 8 | 100.0 | U. of Wisconsin | 1 | 100.0 |
| | | Total | 229 | |

# APPENDIX VIII

# DOCTOR'S DEGREES IN ENGINEERING

**(One-Year Period Ending June 1966)**

(Institutions With At Least One Bachelor's ECPD-Accredited Curriculum)

| No. | Percent of Inst. | Institution | No. of Degrees | Percent of Degrees |
|---|---|---|---|---|
| 1 | 1.0 | Mass. Inst. of Tech. | 173 | 7.5 |
| 2 | 2.0 | U. of Calif. (Berkeley) | 114 | 12.5 |
| 3 | 3.0 | U. of Illinois | 114 | 17.5 |
| 4 | 4.0 | Stanford U. | 106 | 22.1 |
| 5 | 5.0 | Purdue U. | 95 | 26.3 |
| 6 | 5.9 | U. of Michigan | 74 | 29.5 |
| 7 | 6.9 | U. of Texas | 65 | 32.3 |
| 8 | 7.9 | Northwestern U. | 62 | 35.0 |
| 9 | 8.9 | Cornell U. | 55 | 37.4 |
| 10 | 9.9 | Oklahoma St. U. | 53 | 39.7 |
| 11 | 10.9 | U. of Pennsylvania | 50 | 41.9 |
| 12 | 11.9 | Ohio St. U. | 49 | 44.1 |
| 13 | 12.9 | U. of Minnesota | 49 | 46.2 |
| 14 | 13.9 | Carnegie Inst. of Tech. | 48 | 48.3 |
| 15 | 14.9 | Iowa St. U. | 46 | 50.3 |
| 16 | 15.8 | Calif. Inst. Tech. | 43 | 52.2 |
| 17 | 16.8 | Princeton U. | 43 | 54.1 |
| 18 | 17.8 | U. of Wisconsin | 41 | 55.8 |
| 19 | 18.8 | New York U. | 39 | 57.5 |
| 20 | 19.8 | Columbia U. | 35 | 59.1 |
| 21 | 20.8 | Poly. Inst. of Brooklyn | 35 | 60.6 |
| 22 | 21.8 | Texas A and M U. | 34 | 62.1 |
| 23 | 22.8 | Harvard U. | 32 | 63.5 |
| 24 | 23.8 | U. of Washington | 31 | 64.8 |
| 25 | 24.8 | Georgia Inst. of Tech. | 30 | 66.1 |
| 26 | 25.7 | No. Carolina St. U. | 30 | 67.5 |
| 27 | 26.7 | U. of Florida | 29 | 68.7 |
| 28 | 27.7 | Rice U. | 28 | 69.9 |
| 29 | 28.7 | Case Inst. of Tech. | 27 | 71.1 |
| 30 | 29.7 | Michigan St. U. | 27 | 72.3 |
| 31 | 30.7 | Lehigh U. | 24 | 73.3 |
| 32 | 31.7 | Pennsylvania St. U. | 24 | 74.4 |
| 33 | 32.7 | UCLA | 23 | 75.4 |
| 34 | 33.7 | Illinois Inst. of Tech. | 22 | 76.4 |
| 35 | 34.7 | Iowa St. U. | 21 | 77.3 |
| 36 | 35.6 | Syracuse U. | 21 | 78.2 |
| 37 | 36.6 | U. of Maryland | 21 | 79.1 |
| 38 | 37.6 | Rensselaer Poly. Inst. | 19 | 79.9 |
| 39 | 38.6 | Virginia Poly. Inst. | 19 | 80.8 |
| 40 | 39.6 | U. of Oklahoma | 18 | 81.5 |
| 41 | 40.6 | Johns Hopkins U. | 17 | 82.3 |
| 42 | 41.6 | U. of Arizona | 17 | 83.0 |
| 43 | 42.6 | U. of Colorado | 16 | 83.7 |
| 44 | 43.6 | U. of New Mexico | 16 | 84.4 |
| 45 | 44.6 | U. of Delaware | 15 | 85.0 |
| 46 | 45.5 | Kansas St. U. | 14 | 85.7 |
| 47 | 46.5 | Colorado Sch. of Mines | 13 | 86.3 |
| 48 | 47.5 | U. of Rochester | 13 | 86.8 |
| 49 | 48.5 | U. of Tennessee | 13 | 87.4 |
| 50 | 49.5 | Brown U. | 12 | 87.9 |
| 51 | 50.4 | Colorado St. U. | 12 | 88.4 |
| 52 | 51.4 | U. of Connecticut | 12 | 89.0 |
| 53 | 52.4 | U. of Kansas | 12 | 89.5 |
| 54 | 53.4 | U. of Notre Dame | 12 | 90.0 |
| 55 | 54.4 | U. of Southern Calif. | 12 | 90.5 |
| 56 | 55.4 | U. of Utah | 12 | 91.0 |
| 57 | 56.4 | Washington U. | 12 | 91.6 |
| 58 | 57.4 | Stevens Inst. of Tech. | 11 | 92.1 |
| 59 | 58.4 | SUNY at Buffalo | 10 | 92.5 |
| 60 | 59.4 | U. of Virginia | 10 | 92.9 |
| 61 | 60.3 | Vanderbilt U. | 10 | 93.4 |
| 62 | 61.3 | U. of Missouri (Columbia) | 9 | 93.8 |
| 63 | 62.3 | U. of Missouri (Rolla) | 9 | 94.2 |
| 64 | 63.3 | U. of Pittsburgh | 9 | 94.5 |
| 65 | 64.3 | Oregon St. U. | 8 | 94.9 |
| 66 | 65.3 | Arizona St. U. | 7 | 95.2 |
| 67 | 66.3 | West Virginia U. | 7 | 95.5 |
| 68 | 67.3 | Catholic U. of America | 6 | 95.8 |
| 69 | 68.3 | U. of Cincinnati | 6 | 96.0 |
| 70 | 69.3 | Newark College of Engineering | 5 | 96.2 |
| 71 | 70.2 | Rutgers St. U. | 5 | 96.5 |
| 72 | 71.2 | Tulane U. | 5 | 96.7 |
| 73 | 72.2 | U. of Calif. (Davis) | 5 | 96.9 |
| 74 | 73.2 | U. of Houston | 5 | 97.1 |
| 75 | 74.2 | George Washington U. | 4 | 97.3 |
| 76 | 75.2 | Mississippi St. U. | 4 | 97.5 |
| 77 | 76.2 | U.S. Naval Postgraduate Sch. | 4 | 97.6 |
| 78 | 77.2 | U. of Alabama | 4 | 97.8 |
| 79 | 78.2 | U. of Arkansas | 4 | 98.0 |
| 80 | 79.2 | Utah St. U. | 4 | 98.2 |
| 81 | 80.1 | Worcester Poly. Inst. | 4 | 98.3 |
| 82 | 81.1 | Duke U. | 3 | 98.5 |
| 83 | 82.1 | Montana St. U. | 3 | 98.6 |
| 84 | 83.1 | U. of Idaho | 3 | 98.7 |
| 85 | 84.1 | U. of Nebraska | 3 | 98.9 |
| 86 | 85.1 | U. of Rhode Island | 3 | 99.0 |
| 87 | 86.1 | Auburn U. | 2 | 99.1 |
| 88 | 87.1 | Clemson U. | 2 | 99.2 |
| 89 | 88.1 | New Mexico St. U. | 2 | 99.3 |
| 90 | 89.1 | Northeastern U. | 2 | 99.3 |
| 91 | 90.0 | SUNY Coll. of Ceramics | 2 | 99.4 |
| 92 | 91.0 | Texas Tech. Coll. | 2 | 99.5 |
| 93 | 92.0 | U. of So. Carolina | 2 | 99.6 |
| 94 | 93.0 | Wayne St. U. | 2 | 99.7 |
| 95 | 94.0 | Clarkson Coll. of Tech. | 1 | 99.7 |
| 96 | 95.0 | Dartmouth Coll. | 1 | 99.8 |
| 97 | 96.0 | Louisiana St. U. | 1 | 99.8 |
| 98 | 97.0 | U. of Denver | 1 | 99.9 |
| 99 | 98.0 | U. of Louisville | 1 | 99.9 |
| 100 | 99.0 | U. of Maine | 1 | 100.0 |
| 101 | 100.0 | Washington St. U. | 1 | 100.0 |
| | | Total | 2,292 | |

# REFERENCES


## PART A

A-1. Mann, C. R., *A Study of Engineering Education,* Bulletin No. 11, The Carnegie Foundation for the Advancement of Teaching, 1918.

A-2. Wickenden, W. E., *Report of the Investigation of Engineering Education, 1923-1929,* Pittsburgh, Society for the Promotion of Engineering Education, vol. I, 1930, vol. II, 1934.

A-3. Hammond, H. P., "Aims and Scope of Engineering Curricula," *Journal of Engineering Education,* vol. 30, no. 7, March 1940, pp. 555-566.

A-4. Hammond, H. P., "Engineering Education After the War," *Journal of Engineering Education,* vol. 34, no. 9, May 1944, pp. 589-614.

A-5. Grinter, L. E., "Report on Evaluation of Engineering Education (1952-1955)," *Journal of Engineering Education,* vol. 46, no. 1, September 1955, pp. 25-63.

A-6. Burdell, E. S., "General Education in Engineering," *Journal of Engineering Education,* vol. 46, no. 8, April 1956, pp. 619-750.

A-7. "ASEE Grant on Liberal Studies in Engineering," *Journal of Engineering Education,* vol. 58, no. 1, September 1967, p. 42.

## PART B

B-1. Gordon, T. J. and Helmer, Olaf, *Report on a Long-Range Forecasting Study,* P-2982, Rand Corporation, Santa Monica, California, September 1964, pp. 39-40.

B-2. Ibid., pp. 40-41.

B-3. *Scientists, Engineers and Technicians in the 1960's: Requirements and Supply,* NSF Report 63-34. Prepared for the National Science Foundation by the U. S. Department of Labor Bureau of Labor Statistics, p. 31.

B-4. Alden, John D., *Demand for Engineers and Engineering Technicians—1966,* Engineering Manpower Commission, Engineers Joint Council (advanced copy in press).

B-5. LeBold, W. K., Perrucci, R. and Howland, W. E., "The Engineer in Industry and Government," *Journal of Engineering Education,* vol. 56, no. 7, March 1966, pp. 237-273, reprinted as Goals of Engineering Education Information Document No. 7. Appendix B. Question 13.

B-6. Ibid., Appendix B, Question 37.

B-7. Perrucci, R. and LeBold, W. K., "Organizational Views on Recruitment, Employment, and Education of Engineers in Industry and Government," *Journal of Engineering Education,* vol. 56, no. 10, June 1966, pp. 389-407, reprinted as Goals of Engineering Education Information Document No. 8. Question 16, page 403.

B-8. Office of Research, *A Fact Book on Higher Education,* American Council on Education, Washington, D. C., p. 81 (1966), p. 92 (1965) and Dunham, Ralph E., "Engineering Degrees (1964-65) and Enrollments (Fall, 1965)," *Journal of Engineering Education,* vol. 56, no. 6, February 1966, pp. 181-197.

B-9. Flanagan, J. C., et al., *Project Talent: The American High School Student,* Research Project No. 635, Project Talent Office, University of Pittsburgh, 1964, pp. 5-59.

B-10. National Merit Scholarship Board, *Annual Report, 1965,* Evanston, Illinois, 1965, p. 56.

B-11. Blumenfeld, W. S., *Some Characteristics of Finalists in the 1966 National Achievement Scholarship Program,* National Merit Scholarship Corporation, 1966: vol. 2, no. 4, NMSC, Evanston, Illinois, 1965, p. 14.

B-12. Davis, J., *Great Aspirations,* vol. 1, National Opinion Research Center, Chicago, 1963, p. 298.

B-13. Engineers Joint Council, *Engineering Manpower in Profile,* National Science Foundation, Washington, D. C., p. 11.

B-14. *Report on Education and Training of Professional Engineers,* vol. 1, Conference of Engineering Societies of Western Europe and the United States of America (EUSEC), Sept. 1960.

## PART C

C-1. The ideas and some of the phrases of this paragraph have been taken from Brown, J. D., "The Role of Engineering as a Learned Profession," *Journal of Engineering Education,* vol. 54, no. 10, June 1964, pp. 332-333.

C-2. Grinter, L. E., "Report on Evaluation of Engineering Education (1952-1955)," *Journal of Engineering Education,* vol. 46, no. 1, September 1955, pp. 25-63.

C-3. Same as Reference B-7, Table 4, p. 391.

C-4. Same as Reference B-5, pp. 237-73.

C-5. LeBold, W. K., Perrucci, R., Singleton, J., Salvo, V., Howland, W. E. and Hawkins, G. A., "Educational Institutional Views of Undergraduate Goals of Engineering Education," *Journal of Engineering Education,* vol. 56, no. 6, February 1966, pp. 213-227, reprinted as Goals of Engineering Education Information Document No. 5, 1966.

C-6. Foecke, H. A., "Engineering Degree Programs Accredited by ECPD as of October 1965," *Journal of Engineering Education,* vol. 56, no. 8, April 1966, p. 315.

C-7. *Engineering: Cornell Quarterly,* vol. 1, no. 1, Cornell University, Ithaca, N. Y., Spring 1966.

C-8. University of California Advisory Council, *An Engineering Master Plan Study for the University of California,* Berkeley, Calif., 1965.

C-9. Gardner, J. W., *Excellence—Can We Be Equal and Excellent Too?,* Harper Colophon Books, New York, 1961.

C-10. Cooney, T. and Borgman, C., *Survey of Engineering Faculties 1963* (in preparation), Ford Foundation.

C-11. Ibid., pp. 2, 5, 6.

C-12. National Education Association, *Teacher Supply and Demand in Universities, Colleges, and Junior Colleges, 1965.*

C-13. Foecke, H. A., "Engineering Faculty Recruitment, Development and Utilization," *Journal of Engineering Education,* vol. 50, no. 9, May 1960, pp. 757-828.

C-14. Brand, J. R. and Depew, C. A., "Residencies in Engineering Practice," *Journal of Engineering Education,* vol. 56, no. 10, June 1966, pp. 384-386.

C-15. Annual Report to Congress of the Atomic Energy Commission for 1963, p. 270; for 1964, p. 232.

C-16. Lancaster, O. E., "Engineers' Program for Better Teaching," Association for Higher Education *Bulletin,* vol. 18, no. 16, June 1, 1966.

C-17. Kraybill, E. K., *Evaluative Study of Summer Institute on Effective Teaching for Engineering Teachers,* a dissertation for the degree of Doctor of Philosophy, University of Michigan, 1966 (See also "Evaluation of a Summer Institute on Effective Teaching," by E. K. Kraybill, *Journal of Engineering Education,* vol. 58, no. 2, October 1967, pp. 135-138.)

C-18. Powers, N., "Summer Institute Programs for Engineering Teachers," Preliminary Report on ASEE-NASA Summer Institute Programs for Engineering Teachers, 1964, *Journal of Engineering Education,* vol. 55, no. 3, November 1964, p. xv.

C-19. Same as Reference C-5, p. 224.

C-20. LeBold, W. K., Howland, W. E. and Hawkins, G. A., "Reactions to the Preliminary Report of the ASEE Goals Study," *Journal of Engineering Education,* vol. 57, no. 6, February 1967, reprinted as Goals of Engineering Education Information Document No. 9, p. 439.

C-21. Same as Reference C-5, pp. 222-223.

C-22. Ibid., p. 221.

## PART D

D-1. "Educational Attainment: March 1966 and 1965," *Population Characteristics,* Series P-20, No. 158, December 19, 1966, published by the Bureau of the Census, U. S. Department of Commerce.

D-2. Pettit, J. M. and Gere, J. M., "Evolution of Graduate Education in Engineering," *Journal of Engineering Education,* vol. 54, no. 2, October 1963, pp. 57-62.

D-3. Pettit, J. M. and Gere, J. M., "Federal Support of Graduate Engineering Education," *Journal of Engineering Education,* vol. 55, no. 5, January 1965, pp. 164-171.

D-4. Rukeyser, M., *Willard Gibbs,* Doubleday, Doran and Co., Inc., Garden City, N. Y., 1942, p. 136.

D-5. Wheeler, L. P., *Josiah Willard Gibbs,* Revised Edition, Yale University Press, New Haven, Conn., 1952, p. 32.

D-6. John, W. C. and Hammond, H. P., "Graduate Work in Engineering in Universities and Colleges in the United States," Office of Education, *Bulletin 1936,* no. 8, U. S. Government Printing Office, Washington, D. C., 1936, p. 1.

D-7. LeBold, W. K., Perrucci, R., et al., "Educational Institutional Views of Undergraduate Goals of Engineering Education," *Journal of Engineering Education,* vol. 56, no. 6, February 1966, pp. 213-227.

D-8. LeBold, W. K., Perrucci, R. and Howland, W. E., "The Engineer in Industry and Government," *Journal of Engineering Education,* vol. 56, no. 7, March 1966, pp. 237-273.

D-9. "Science and Engineering Staff in Universities and Colleges, 1965-75," National Science Foundation, NSF 67-11, Washington, D. C., May 1967, p. 14.

D-10. "Higher Education and National Affairs," American Council on Education, Washington, D. C., vol. 16, no. 24, June 30, 1967, p. 3.

D-11. Wolfle, D., *America's Resources of Specialized Talent,* Harper and Bros., New York, 1954, pp. 142-146.

D-12. Brown, H., Bonner, J. and Weir, J., *The Next Hundred Years,* Viking Press, New York, 1963, Chap. 15.

D-13. Harmon, L. R., "High School Backgrounds of Science Doctorates," *Science,* vol. 133, March 10, 1961, pp. 679-688.

D-14. Harmon, L. R., "The Supply of Brains," *International Science and Technology,* February 1966, pp. 80-84.

D-15. Cartter, A. M., *An Assessment of Quality in Graduate Education,* a report of the American Council on Education, Washington, D. C., 1966, 131 pages.

D-16. Perrucci, R., LeBold, W. K. and Howland, W. E., "Organizational Views on Recruitment, Employment, and Education of Engineers in Industry and Government," *Journal of Engineering Education,* vol. 56, no. 10, June 1966, pp. 389-407.

D-17. *Continuing Engineering Studies,* a report of the Joint Advisory Committee on Continuing Engineering Studies (ECPD, EJC, ASEE, NSPE), E. Weber, Chairman, 112 pages. Published by Engineers Council for Professional Development, March 1966.

D-18. *The Master's Degree,* a statement by the Council of Graduate Schools in the United States (undated; circa 1965).

D-19. *Teacher Supply and Demand in Universities, Colleges, and Junior Colleges, 1961-62 and 1962-63,* Research Report 1963-R3, National Education Association, May 1963.

D-20. *The California Engineering Graduate, A Study of the Engineering Alumni of the University of California, Berkeley, and University of California, Los Angeles, Classes of 1949-1962,* Department of Engineering, University of California, Los Angeles, 1965.

D-21. *Manual of Graduate Study in Engineering,* prepared by the Graduate Committee of the American Society for Engineering Education, L. E. Grinter, Chairman, 1952, 36 pages.

D-22. *Facilities and Opportunities for Graduate Study in Engineering,* a report of the Graduate Study Commission of the American Society for Engineering Education, N. A. Hall, Chairman, March 1958, 37 pp.

D-23. Berelson, B., *Graduate Education in the United States,* McGraw-Hill Book Co., Inc., New York, 1960, 346 pages.

D-24. *The Doctor of Philosophy Degree,* a statement by the Association of Graduate Schools in the Association of American Universities and the Council of Graduate Schools in the United States (undated; circa 1965).

D-25. *The Doctor's Degree in Professional Fields,* a statement by the Association of Graduate Schools in the Association of American Universities and the Council of Graduate Schools in the United States (undated; circa 1966).

D-26. *An Engineering Master Plan Study for the University of California,* by the Engineering Advisory Council, University of California, September 1, 1965, 178 pages.

D-27. "Doctoral Education in Chemistry," *Chemical and Engineering News,* vol. 42, May 4, 1964, pp. 76-84.

D-28. *Report on Evaluation of Engineering Education,* prepared by the Committee on Evaluation of Engineering Education, L. E. Grinter, Chairman, on behalf of the American Society for Engineering Education, 1955, 36 pages.

D-29. *Physics in the Four-Year Colleges,* a report of the Committee on Physics Faculties in Colleges, American Institute of Physics, 335 East 45 Street, New York, N. Y., Publication R-187, December 1965, 24 pages.

D-30. *Doctorate Production in United States Universities, 1960-62,* Publication No. 1142, National Academy of Sciences—National Research Council, Washington, D. C., 1963, 215 pages.

D-31. Wilson, W. E. and Landau, J., "Origin of Engineering Ph.D.'s in 1965," *Journal of Engineering Education,* vol. 56, No. 9, May 1966, pp. 342-344.

D-32. *The Merit Program: The First Decade,* Annual Report for 1965, published by the National Merit Scholarship Corporation, 990 Grove Street, Evanston, Illinois, 60201.

D-33. *New Doctor of Philosophy Degree Programs,* a statement by the Council of Graduate Schools in the United States (undated; circa 1966).

D-34. LeBold, W. K., Howland, W. E. and McCarthy, J. L., "Accreditation Related to Engineering and Graduate Education: A Historical Review," *Journal of Engineering Education,* vol. 55, no. 6, February 1965, pp. 175-187.

D-35. Engineers' Council for Professional Development, *35th Annual Report for the Year Ending September 30, 1967,* pp. 15-17.

## APPENDICES

III-1. "Computers in Engineering Education," synopsis of the report from the ECAC-ECRC Information Systems Committee, *Journal of Engineering Education,* vol. 56, no. 8, April 1966, p. 319.

III-2. Same as Reference B-5, Figure 12, p. 244.

III-3. Ibid., Figure 11, p. 244.

III-4. Reinhard, P. M., *Engineering Graphics Course Content Development Study—Final Report, 1965,* NSF Grant 1862, University of Detroit, 1965.

III-5. Sutherland, I. E., *Sketchpad, A Man-Made Graphical Communication System,* Lincoln Laboratory, MIT, Cambridge, Mass.

III-6. Smith, C. F., "The Computer in Design Engineering," *Mechanical Engineering,* vol. 86, no. 4, April 1964, p. 31.

III-7. Same as Reference B-5, Figures 17 and 18, p. 247.

III-8. Same as Reference C-5, p. 225.

III-9. Alger, P. L. et al., *Ethical Problems in Engineering,* John Wiley and Sons Inc., 1965.

IV-1. Dunham, R. E., "Engineering Degrees (1964-65) and Enrollments (Fall, 1965)," *Journal of Engineering Education,* vol. 56, no. 6, February 1966, p. 181.

IV-2. Foecke, H. A., "Recent Developments in Engineering," a paper delivered at the Conference on New Developments in College Education in Mathematics, Physical Sciences and Engineering, held at the University of California at Los Angeles, November 2, 1963.

IV-3. Same as Reference B-7, Appendix A, Question 4, p. 400.

IV-4. Same as Reference B-3, p. 8.

IV-5. Engineering Manpower Commission, "Technician Lag Intensified Crisis," *Engineering and Scientific Manpower Newsletter,* no. 132, April 1963.

IV-6. Patrick, P., "Tenth Annual Survey of Engineering-Technician Enrollment and Graduation," *Journal of Engineering Education,* vol. 55, no. 1, September 1965, pp. 14-15.

IV-7. Defore, J. J., "Baccalaureate Programs in Engineering Technology: A Study of Their Emergence and of Some Characteristics of Their Content," unpublished, Florida State University, 1966.