

APPENDIX

Summary of the Report on Evaluation of Engineering Education*

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Engineering Education must contribute to the development of men who can face new and difficult engineering situations with imagination and competence. Meeting such situations invariably involves both professional and social responsibilities. The Committee considers that scientifically oriented engineering curricula are essential to achieve these ends and recommends the following means of implementation:

1. A strengthening of work in the basic sciences, including mathematics, chemistry, and physics.
2. The identification and inclusion of six engineering sciences, taught with full use of the basic sciences, as a common core of engineering curricula, although not necessarily composed of common courses.
3. An integrated study of engineering analysis, design, and engineering systems for professional background, planned and carried out to stimulate creative and imaginative thinking, and making full use of the basic and engineering sciences.
4. The inclusion of elective subjects to develop the special talents of individual students, to serve the varied needs of society, and to provide flexibility of opportunity for gifted students.
5. A continuing, concentrated effort to strengthen and integrate work in the humanistic and social sciences into engineering programs.
6. An insistence upon the development of a high level of performance in the oral, written, and graphical communication of ideas.
7. The encouragement of experiments in all areas of engineering education.
8. The strengthening of graduate programs necessary to supply the needs of the profession, conducted in those institutions that can:
 - a. provide a specially qualified faculty,
 - b. attract students of superior ability, and
 - c. furnish adequate financial and administrative support.
9. Positive steps to insure the maintenance of faculties with the intellectual capacity as well as the professional and scholarly attainments necessary to implement the preceding recommendations. These steps include:
 - a. well-established recruitment, development, and evaluation procedures,
 - b. favorable intellectual atmosphere, reasonable teaching loads, and adequate physical facilities, and
 - c. salary scales based on the recognition that the required superior faculty can be secured only by competitive remuneration, since professional practice in industry and government is inherently

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attractive to the best minds in engineering.

10. The consideration of these recommendations at this time before the problems of educating greatly increased numbers of engineers become critical.

Report of the Committee on Evaluation of Engineering Education

I. OBJECTIVES OF ENGINEERING EDUCATION AND THEIR IMPLEMENTATION

The Committee on Evaluation of Engineering Education of the American Society for Engineering Education (ASEE) was appointed in May, 1952, by President S. C. Hollister. This action followed a recommendation of the 1951 ECPD Committee on Adequacy and Standards of Engineering Education and also followed discussions within the Engineering College Administrative Council of ASEE, the Education Committee of ECPD, and the General Council of ASEE. The charge to the Committee was to recommend the pattern or patterns that engineering education should take in order to keep pace with the rapid developments in science and technology and to educate men who will be competent to serve the needs of and provide the leadership for the engineering profession over the next quarter-century.

The Committee on Evaluation began its work in June 1952, at the Dartmouth meeting of ASEE. The Education Committee of ECPD immediately requested the Committee to give consideration to the development of standards that might aid ECPD in bringing engineering accreditation in consonance with future responsibilities of engineers. The Committee on Evaluation was asked particularly to clarify the curriculum content that differentiates engineering education from that in science on the one hand or in subprofessional technology on the other.

In order to enlist the aid of engineering educators throughout the United States in this important undertaking, the Deans of all engineering colleges having accredited curricula were invited to appoint Institutional Committees to conduct their own studies on evaluation of engineering education. A series of questions expressing the broad problems confronting engineering education was sent to these Institutional Committees to form the basis of exploration. The discussion of these questions by the Institutional Committees and the ASEE Committee culminated in the preparation of a series of institutional reports and in the Preliminary Report on Evaluation of Engineering Education, which was issued in October, 1953.

This Preliminary Report was distributed for critical review to all colleges with accredited engineering curricula. The response of the institutions was extraordinary and resulted in an extended analysis that was nation-wide in scope. Reports embodying the criticisms which developed were received from 122 Institutional Committees. Study of these recommendations by the main Committee aided it in understanding the nation-wide thought of engineering educators. Many of these recommendations and those expressed in the previous evaluation studies outlined in Appendix A, together with those of the

Committee itself, formed the basis for an Interim Report on Evaluation of Engineering Education published in June 1954. Critical review of the Interim Report was sought and obtained. All institutions were asked to review the Report and submit criticisms. Several hundred copies were mailed to as many industrial concerns with requests for criticisms. Over eight thousand copies of the Interim Report were purchased in the first four months, which indicated both the wide interest of faculties in the Report and the extent of its distribution. It was also placed in the hands of all ASEE members by publication in the September 1954, *Journal of Engineering Education*.

From the comments received from individuals, Institutional Committees, industrial companies, and societies, the Committee has concluded that the Interim Report has been accepted as pointing the trend for the evolution of engineering education over at least the next decade. Hence, this final Report follows basically the same line of development as the Interim Report. However, the comments received indicated two weaknesses that are believed to have been remedied.

First, the Interim Report failed to give adequate emphasis to the graduate phase of engineering education. This weakness has been corrected by expanding the former section on graduate work. However, since this new section in the final Report deals only broadly with graduate study, it is recommended that those interested in the details of graduate education refer to *A Manual of Graduate Study in Engineering*, published in 1945 as an ASEE Committee Report (*Journal of Engineering Education*, Vol 35, p. 650) and reissued in 1952 in monograph form.

Secondly, comments which were received, particularly from industry, place great emphasis upon the inability of engineers to express themselves in clear, concise, effective, and interesting language. Stress was also placed upon the importance to engineers of an acquaintance with the humanities and social sciences. This has led the Committee to reconsider the place of non-technical studies in an engineer's education, with the result that this final Report places greater emphasis on humanistic and social study and effective communication. Since a special investigation of humanistic and social studies in engineering education is being conducted by another ASEE committee, the subject is treated broadly rather than in detail in this Report.

Studies were also made and comments received from committees appointed by other societies at the request of the Committee to consider the teaching of physics and of mathematics to engineers. The American Association of Physics Teachers (AAPT), the American Institute of Physics (AIP), the Mathematical Association of America (MAA), and the ASEE Divisions of Physics and Mathematics all had committees participating in these studies. Although only one of these was a joint committee, the others served this purpose because of the overlapping membership involved and the joint meetings scheduled. The ASEE requested the National Science Foundation to support various conferences in these areas. Its generous response in supplying the needed funds and the enthusiastic cooperation of the committees made additional comments available which assisted the Committee in formulating the revisions incorporated in this final Report.

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the General Electric Company, the National Science Foundation, and the General Council of ASEE for the financial assistance which made this study possible.

A. Objectives of Engineering Education

The determination of the pattern which engineering education should take in the future must, of necessity, be based upon the obligations of the engineering profession to society and upon the importance of the development of the student as an individual. The obligations of an engineer as a servant of society involve the continual maintenance and improvement of man's material environment, within economic bounds, and the substitution of labor-saving devices for human effort. Moreover, his activity usually has a direct bearing on the welfare and safety of large segments of society. Like the physician, the engineer must work within the current limitations of the state of his art and must decide which one of several possibilities provides the best solution to a given problem.

Engineering is far from static, for it is essentially a creative profession. It has played a dominant role in building American industrial superiority, in developing the principle of mass production, and in giving the American people their high standard of living. The continuing growth of our knowledge of basic science has opened vast new areas to engineering endeavor and has enlarged the foundations underlying many of the existing engineering fields. Some fields of engineering have been reasonably alert in assimilating new scientific advances into their teaching programs. It is one purpose of this Report to encourage all fields of engineering education to move in this direction.

Any attempt to specify the content of an engineering curriculum must be preceded by the development of a clear understanding of the objectives of such professional education. These objectives are two-fold and are based on the technical and social responsibilities that must be assumed by graduates expecting to enter the engineering profession. The entire professional educational process is more inclusive in scope than an undergraduate engineering curriculum, for it also includes training in high school and post-baccalaureate study in a university or in industry, along with continual self-study and with experience in engineering practice before full professional status can be achieved.

Technical and Social Objectives—The first objective, the technical goal of engineering education, is preparation for the performance of the functions of analysis and creative design, or of the functions of construction, production, or operation where a full knowledge of the analysis and design of the structure, machine, or process is essential. It also involves mastery of the fundamental scientific principles associated with any branch of engineering, including a knowledge of their limitations and of their applications to particular problems, such as the development of materials, machines, or structures as well as the ability to make critical scientific and economic analyses and to organize these into clear, concise, and convincing oral or written reports.

The second objective, the broad social goal of engineering education, includes the development of leadership, the inculcation of a deep sense of professional ethics, and the general edu-

cation of the individuals. These broad objectives include an understanding of the evolution of society and of the impact of technology on it; and acquaintance with and appreciation of the heritage of other cultural fields; and the development of both a personal philosophy which will insure satisfaction in the pursuit of a productive life and a sense of moral and ethical values consistent with the career of a professional engineer.

These technical and social objectives should be met in a manner which will provide the individual with an enlightened background that will give him the means and the inspiration to grow on his own initiative before and after graduation. An undergraduate curriculum must serve a two-fold purpose of preparing some men for immediate employment and others for graduate study. This Committee believes that in any one field a curriculum with a reasonable degree of flexibility, as represented by electives, can meet both of these needs.

B. Implementation of Objectives

A number of factors influence the effectiveness of engineering education. Of these, the selection and development of a faculty and the relation of the curricular content to the objectives of engineering education have received the greatest emphasis in the nation-wide discussions that have taken place, and they form the central theme of this Report. Admission requirements, high school-college articulation, existence of adequate facilities, provision for gifted students, and the significance of graduate programs are also considered for their effect on the implementation of any suggested changes in present programs. Nevertheless, thoughtful consideration inevitably leads to the conclusion that the character and quality of the faculty are of controlling importance. Therefore, the selection and development of the faculty is considered first.

II. THE SELECTION AND DEVELOPMENT OF AN ENGINEERING FACULTY

Distinguished faculties are far more important to the advancement of engineering education than details of curricula or magnificence of facilities. The university is a community of scholars and as such requires outstanding teachers to attract outstanding students. To improve and develop courses or curricula, to build up facilities—in short, to command respect as an educational institution—all require a faculty of competent teachers and scholars.

A thoroughly competent faculty can be acquired and maintained only if the college administration gives discriminating attention to the important problems of recruitment, selection, training, advancement, and termination of appointment. Logically, however, the selection of competent staff members can be undertaken only after long-range curricular objectives have been formulated.

A. University and College Environment

The academic and professional development of an engineering faculty can proceed only in a favorable environment. More important than physical surroundings is the intellectual atmosphere; that is, the attitudes and ideas of the people who com-

prise the university. A common inner urge to know and to understand is basic to this atmosphere and leads to unity of purpose—the mutual selection of common goals and coordination of effort toward their achievement. There must be encouragement of intellectual growth and opportunity for professional development such as is involved in the teaching of graduate courses. Teaching loads must be kept at reasonable levels to allow time for scholarly or creative activities. The development of such a favorable academic atmosphere should be the concern of all faculty members, particularly those in senior administrative posts.

Physical surroundings also contribute to a favorable environment. Facilities may be modest or extensive, as long as they are in harmony with and effectively serve the curricula. Besides adequate classrooms and laboratories, the individual teacher needs appropriate office space, research facilities, technical services, secretarial help, and an effective library. An adequate library, its accessible location, and its required use are essential elements in any educational process.

The atmosphere of a university has a significant influence on student progress. Students need a close bond of mutual interest and friendship with members of the faculty. They need objective guidance and encouragement in their intellectual growth; they need sympathetic understanding of their personal problems; but above all, they need the realization that they are being treated as individuals. An administration and a faculty which are genuinely concerned with these responsibilities are most likely to create a favorable student environment.

B. Qualifications of Teachers

Any teacher at the university level must have notable intellectual capacity and a sustained interest in a life of study for continuing mastery of his field—obvious qualifications that nevertheless merit explicit statement. To teach well, he must know and understand, clearly and in perspective, his own and supporting fields at a much more penetrating level than that required in his lectures.

The engineering teacher, in addition, must have a full appreciation of the goals to be achieved. He should realize, first of all, that a course can be taught either as a narrow specialty or as a liberal subject in a professional curriculum; he should strive for the latter. Such a liberal course is one in which the teacher inspires his students toward creative endeavor and intellectual development not only while they are in college but also throughout their careers. It is one into which he brings recognition of the importance of intellectual honesty and professional integrity. To achieve these goals he should possess energy, enthusiasm, and a sincere interest in the development of men. To be fully successful he must exercise judgment and tact, and have the ability to meet the minds of his students. He *should perform creative work whether it be in teaching, writing, research, or professional activities.*

The selection of individuals for faculty appointments requires a careful evaluation of the qualifications. Good teachers have always been personally creative and capable of inspiring their students to creative endeavor. In the past they necessarily emphasized the art or practice of engineering. However,

during the lifetime of present faculties the art of engineering has come to depend greatly upon basic and engineering science. It must also be recognized that universities are better equipped to teach the science underlying professional practice, whereas industry is better adapted to provide experience in practical applications. Within a faculty there should exist a balance of experience in both the science and the art of engineering.

C. Education and Experience

For a relatively young candidate for a faculty position, the strongest evidence usually available to measure a background of integrated fundamental knowledge and probable creative ability in teaching and research is an education which includes the doctor's degree. However, unless an academic environment is provided that will stimulate and retain men with an interest in creative work, mere insistence on degrees will not insure high quality in a faculty. For experienced persons, evidence of the capacity of the individual for creative teaching and research may be gauged by other criteria, and the formal educational background is of less significance.

Young engineering teachers who hold only the bachelor's degree should be employed only in a temporary position that presupposes a continuation of their education. Lack of such progress should be sufficient reason for terminating their appointments.

Appropriate professional experience in industry, government, or private practice is important in a well-balanced faculty. This experience should be considered in the selection and advancement of individuals, but it need not be a requirement for faculty members with a special educational background or with demonstrated creative ability in research or teaching. Every teacher, regardless of his background, should strive to become a recognized expert in his field. There is no substitute for knowledge of subject matter far beyond the limitations of that to be taught. However, it is recognized that mastery of subject matter alone will not guarantee good teaching and that neither industrial experience nor advance degrees are adequate criteria in themselves. The minimum essentials for good teaching are the mastery of subject matter and the capacity of the teacher to draw students into active participation in the learning process. Strong individuality is often characteristic of distinguished teachers, but the capacity to cooperate with colleagues in carrying out the institutional program as a whole is nevertheless of great importance. The special qualifications of teachers participating in the graduate program are referred to in the graduate section of this Report.

D. Recruitment of a Faculty

Of paramount importance to any profession is the personnel of that profession. No time can be spent more profitably by administrative officers than that required for recruiting and developing competent teachers. Recruitment of a faculty embraces the search for persons whose abilities, aptitudes and personalities are of the desired type; telling them of the opportunities, environment, obligations, and limitations of the pro-

fession; ascertaining whether their ideals and ambitions are consonant with those of the profession and the school; and, finally, arranging suitable compensation for and other terms of employment.

New teachers are often recruited from among those students who have just finished study of a part of the wide field of engineering and science. It is recommended that promising undergraduate and graduate students be sought out and their aptitudes as potential teachers be appraised early in their schooling. If a student's interest is aroused in a teaching career, his study may be guided to embrace breadth of view and scholarly attitude. Such a program should help to recruit and develop teachers who will carry the responsibility of improving engineering education to meet the needs of the future. Care should be exercised to avoid excessive inbreeding: *heterogeneity of faculty backgrounds is inherent in the very concept of a university.*

The effective recruitment and retention of a qualified faculty will require, in colleges of engineering, the establishment of a salary scale comparable to the income earned by outstanding practicing professional engineers as indicated by the published surveys of national societies. Accepted practices in establishing adequate faculty salary scales in the professions of medicine and law indicate that competitive situations must be met if professional education is not to stagnate. It should be recognized that, in contrast with the situation in many academic fields, industry is inherently attractive to many of the best engineering minds. Unless the salary differential is minimized, a sufficient number of superior engineers will not be attracted to or retained in the teaching field, to the detriment of the whole profession, of industry, and of the nation.

In faculty recruitment, industrial or other experience is an important measure of professional qualification. However, one needs to look very closely at the nature and character of this experience to determine its relevance to engineering teaching. Of greatest significance is not the number of years of experience, or even the administrative responsibility that the individual may have carried, although these are not unimportant, but rather evidence of the use of intellectual qualities in professional practice, such as creative design or development, including patents, and research contributions involving reports and publications, or other experience of an analytical or creative nature. One might appropriately ask the following questions. Can the potential teacher articulate his engineering work with the underlying basic science and engineering science? Has his work been such that it has kept his background of science alive or, better yet, in continuous development? Many practicing engineers achieve results by the use of a kind of intuitive sense which, no matter how successful in practice, cannot be transformed into organized knowledge that can be taught to engineering students.

E. Development of a Faculty

Even though the environment and salary scale of an engineering college may be such as to attract and retain an outstanding faculty, the newer members of such a group will usually need guidance in the techniques of teaching. Their study of the ASEE Report on the *Improvement of Teaching* (*Journal of Engineering Education*, Vol. 43, No. 1, Sept., 1952) should

greatly enhance the effectiveness of their teaching. The primary purpose of an engineering college is to provide effective instruction in subject matter through the stimulation and motivation of students, and it is essential that those selected to teach be trained properly for this function. Such instruction may be made more effective by proper organization of subject matter, by teaching elementary as well as advanced courses in a given field, and by teaching subjects in related fields. *The teacher's own use of and insistence on the student's use of clear English, both oral and written, should be considered as an essential part of his teaching of any subject.*

Although experienced teachers will generally perform more effectively than young instructors or graduate assistants, it is possible to achieve excellent results with the latter. Graduate student teachers usually bring into the classroom a youthful vigor, an enthusiasm, and a fresh point of view that are highly commendable. They may also lack professional judgment and maturity to such an extent that they may not give the undergraduate student a sufficiently balanced kind of teaching. However, with careful selection and supervision of assistants and through course organization it is possible to provide competent instruction by teaching assistants. The teaching assistant must accept a responsibility as great as he would have in industry and should be asked to recognize his teaching job as a principal occupation, along with that of graduate study. Furthermore, teaching is a beneficial part of the educational experience even for those who later elect industrial pursuits.

Seminars, discussion groups, formal and informal conferences between experienced and inexperienced teachers can all be used effectively for the development and growth of a faculty. Informality in such arranged programs has merit so long as it does not lead to irregular participation. To maintain interest, such programs must be varied in form from semester to semester.

It is important that faculty members set an example for their students by their membership and active participation in professional and technical societies, by becoming licensed engineers, by study of current literature, and by demonstrating interest in new developments and in research. Such leadership among faculty members is particularly necessary in institutions that are able to provide only limited opportunities for research, for leadership contributes an important element of vitality to teaching. The spirit of leadership that also creates in the student a desire to lead is of the greatest importance. It can be developed by teachers who are men of stature, judgment, wisdom and tact. The ambition for leadership should involve ascendance in a technical field and a desire to serve society.

In engineering teaching, continual contact with the forefront of engineering and scientific progress is essential. Leadership in scientific and engineering progress has frequently stemmed from university research activities. *The engineering teacher carries a responsibility to contribute to the advancement of knowledge through engineering research. The university must provide the opportunity to realize this objective in terms of time, facilities, and assistance.*

It is only when teachers of professional subjects are recognized as experts that they have an opportunity to do consulting work. Hence, the ability to engage in such consultation is not considered to be a major factor in the recruitment of young

teachers. Consulting practice should be considered as a means of developing and further strengthening an engineering faculty. Close association with engineering work or research in industry should stimulate the teacher and improve his teaching. Consulting is also a source of ideas for research. The limit upon the useful extent of this activity has not been determined. However, the belief is widely accepted that an average of one day per week of the individual teacher's time devoted to consulting activity of a high professional character will reflect to the overall advantage of the institution.

F. Evaluation of a Faculty

Evaluation of the potential of prospective faculty members and of the achievement of the existing staff ranks with the development of a progressive atmosphere as a most important function of a university administrator. Systematic and regular methods of evaluation rather than haphazard ones are essential as a guide for recruitment and for making salary adjustments and promotions. Definite policies on termination of appointment for those who do not live up to their expected performance are also necessary for proper development of a strong faculty.

It would be most desirable if this evaluation could be done on a quantitative basis, but the Committee is not aware of any systems which warrant recommendation for general adoption. The Committee suggests that there be more experimentation by individual institutions in the development of quantitative systems of faculty evaluation. Any evaluation system can serve only as a partial guide, since personal judgments must remain the most important factor. The Committee recommends that such quantitative systems as are developed be reported at meetings of the Society and in the Journal. The success of some industrial evaluation systems indicates that there is hope for progress in this area.

The fact that evaluation of the progress of a faculty member must be based on judgment involving many factors indicates that administrators at each level should inform themselves of the viewpoints of their faculties before reaching these judgments, realizing that there are dangers in judgments made by associates of the individual concerned. In particular, the faculty should be informed as completely as possible concerning the methods used in evaluation.

Evaluation, to be effective, should be objective, and it should include along with other factors all the items mentioned in the section on Qualification of Teachers, with emphasis upon:

1. The effectiveness of the individual's teaching based upon his knowledge of subject matter, intellectual capacity, judgment, professional and personal stature, and qualities of personal leadership as shown in his ability to inspire students.
2. His productivity in research and other creative areas including new methods of presentation of subject matter.
3. His professional development as evidenced by progress in early years toward advanced degrees, by accomplishments in engineering practice, or by attainments and recognition as a scholar in his field.
4. His significant publications.
5. Evidence of his professional interest as shown by his

activity in professional societies and in governmental and community affairs, and by his registration as a professional engineer.

6. The nature and responsibility of his consulting services to other areas of the university and to outside organizations.

It is important that administrators periodically advise members of the staff regarding their standing, particularly those members who should be encouraged at an early date to abandon a teaching career. Mere lack of promotion or of salary advances should not be assumed as a sufficient method of criticism for individuals who are not developing according to the standards expected.

It is equally important to stimulate the good teacher by verbal or written approbation, either for his general progress or for his special accomplishments. *It is essential that those staff members endowed with energy and enthusiasm combined with high technical ability that is applied in a creative manner be compensated in the fullest measure.*

An adequate staff either in a departmental faculty that is responsible for a curriculum or in a major supporting group will have at least one teacher in every five who has attained professional distinction. Such individuals will (1) be conducting high-grade research of an engineering or education nature, or other creative activity, including publishing work of good quality, (2) be engaged in consulting work at a creative level, (3) be exercising leadership in scientific, educational, and professional societies, or preferably, (4) be serving in a combination of such activities.

III. CURRICULAR CONTENT AS RELATED TO THE OBJECTIVES OF ENGINEERING EDUCATION

A. Instructional Goals

The ultimate goal of engineering education is the development of able and responsible men fully competent to practice on a professional plane, especially those who will eventually lead the profession to new heights of accomplishment through creative practice or research. The student, not the curriculum, is the primary concern, yet the curriculum has an important influence on education. Before considering curricular components, the instructional goals toward which they are directed should be examined.

The instructional goals of engineering education include helping the student to learn to deal with new situations in terms of fundamental principles, on his own initiative, with confidence and sound judgment. The goals should include motivation to keep abreast of the new developments in science and technology and to continue to grow intellectually in both professional and cultural areas throughout life.

In professional engineering practice the "new situation" often involves social and economic as well as technical elements, and these are not entirely separable. Thus the end result is not merely the numerical solution of a technical problem but is rather a decision based on a value judgment to which the quantitative technical result contributes one important element. In fact, the significant problems involving engineering seldom occur in well-defined form. Hence, the initial stage of

thinking is often an intuitive groping to identify specific component problems. Their solution, in turn, requires the application of thoroughly understood fundamental principles and well-ordered analytical thinking in defining the problem, planning its simplification without losing its essential nature, conceiving a method of an attack, carrying the study through to a successful conclusion, and checking the results at each stage. This technical solution is then available to guide the engineer when he considers the broader social and economic aspects of the problem. His final decision will be influenced by the extent to which his perspective and judgment transcend purely technical matters.

Engineering educators must never lose sight of the broad issues with which large engineering problems are always associated, although the ability to deal effectively with such broad issues comes only with experience and maturity in the years after college. The importance of keeping such economic and social ideas before students by example can hardly be over emphasized. Such concepts should be encompassed even though the main effort at the undergraduate level is largely restricted to developing the student's ability to master the scientific and technical aspects of engineering education. In what follows, therefore, these disciplines are emphasized even though they are but a portion, although a vital one, of the total education that the successful engineer acquires in college and throughout his subsequent professional career.

B. Assimilating New Scientific Material

The evolution of engineering curricula has been characterized by a continuous process of assimilation of new scientific and technological knowledge. Such innovations have necessitated the development of new concepts or shifts to more fundamental and scientific approaches. It seems evident that the frontiers of science and technology are now advancing at a more rapid rate than at any previous time, and that many of today's frontiers will be reduced to significant engineering practice in the years ahead. Furthermore, these newly developed frontiers illuminate the older fields with new concepts and give them increased vitality. It is a responsibility of the engineer to recognize those new developments in science and technology that have significant potentialities in engineering. Moreover, the rate at which new scientific knowledge will be translated into engineering practice depends, in a large measure, upon the engineer's capacity to understand the new science as it develops.

This translation of new scientific developments into engineering practice will be facilitated by emphasizing unity in scientific subject matter. For example, there is a great deal of similarity, both in conceptual understanding and in analytical methods, among the generalizations of heat flow, mechanics of fluids, electromagnetic fields, and vibration theory. When a student understands these generalizations, he has gained a concept of systematic orderliness in many fields of science and engineering; he is therefore able to approach the solution of problems in widely diverse fields, using the same analytical methods. This unification of methods of analysis can be accomplished to a considerable degree without reaching beyond undergraduate mathematical levels. It can be accom-

plished to a much greater degree by utilizing advanced mathematical concepts.

C. Breadth of Engineering Education

Looking at the subject of instructional goals even more broadly, one concludes that the engineer should be a well-educated man. He must be not only a competent professional engineer, but also an informed and participating citizen, and a person whose living expresses high cultural values and moral standards. Thus, the competent engineer needs understanding and appreciation in the humanities and in the social sciences as much as in his own field of engineering. He needs to be able to deal with the economic, human, and social factors of his professional problems. His facility with, and understanding of, ideas in the fields of humanities and social sciences not only provide an essential contribution to his professional engineering work, but also contribute to his success as a citizen and to the enrichment and meaning of his life as an individual. Hence, instructional goals include motivating students and providing them with stimulating opportunities to gain understanding and appreciation of our historical and cultural heritage. This requires that the faculties of the humanities and the social sciences regard the teaching of engineering students as challenging and rewarding, and the engineering faculty members adopt an appreciative and understanding attitude toward their colleagues in the liberal arts.

It is clearly recognized that many engineers progress into managerial and top executive positions in industry and government. For such individuals the foundation should be laid in college for an understanding of human relationships, the principles of economics and government, and other fields upon which the engineering manager can build. The foundation may be built more solidly in humanistic and social courses than in highly applied studies in management.

Education for the profession of engineering does not stop with the acquisition of a degree; it must continue throughout life. Hence, one of the significant instructional goals of engineering education is to motivate the student to learn on his own initiative.

D. Curricular Areas and Content

The preceding discussion of instructional goals clearly indicates that certain curricular areas are obviously basic to undergraduate engineering education. These areas include mathematics and the basic sciences, the engineering sciences, the application of these sciences to the analysis and synthesis of engineering systems within the student's major field, technical courses outside his major field, and humanistic and social studies.

The following paragraphs describe briefly the more important components of an engineering curriculum and give a rough indication of the broad curricular content and approximate level that appear to be appropriate to an undergraduate curriculum. *These paragraphs are not intended as a statement of rigid requirements, since the Committee recommends widespread experimentation. However, significant departures from these recommendations should be accepted only on the basis of clearly stated*

educational objectives.

E. The Basic Sciences

The basic sciences which make up the foundation of engineering curricula are usually considered to include mathematics, physics, and chemistry. These studies and the level of instruction contemplated in each are discussed below. *In general the basic sciences will total about one fourth of the undergraduate program.*

Mathematics—Casual perusal of current professional journals is sufficient to show that all branches of engineering are continually becoming more dependent upon mathematics of an increasingly high level. In fact, engineering judgment is more and more often guided by mathematical analysis, and such analysis is rapidly expanding the demands it places upon advanced areas of mathematics. At the undergraduate level, competence is the theory and use of simple, ordinary differential equations and their application to the solution of physical problems lies close to the boundary of *minimum* acceptability of mathematics in any satisfactory engineering curriculum. For students who will be chiefly interested in research, development, or the higher phases of analysis and design, or who contemplate subsequent graduate study in engineering, additional mathematics may be both desirable and necessary.

A minimum level of performance in mathematics should be established, whether it be obtained in required mathematics courses or in engineering courses. However, few engineering courses are taught in a manner to make a significant contribution to the student's knowledge of basic mathematics, nor is time available for this purpose. The engineering sciences and subsequent professional subject matter should be developed by making effective use of such mathematical proficiency and should be taught by staff members who have this proficiency.

Physics—Too often, physics as presently taught to engineers barely touches upon the many new physical concepts which have been developed during the past generation and which today strongly influence engineering practice. *Modern physics, including an introduction to nuclear or solid-state physics, should be a part of undergraduate engineering curricula.* As a contribution to making this presentation to engineers as effective as possible in a limited time, it is believed that the basic course in physics needs a new orientation. The duplication between classical physics and the engineering sciences of mechanics, thermodynamics, and electricity can be largely removed if the objective of the introductory physics course is redirected to place much greater emphasis upon sub-microscopic phenomena and the conservation principles, with virtual elimination of semi-engineering examples. An introductory course in physics that attempts to be a tool subject for engineering mechanics, thermodynamics, and electricity appears to serve less and less purpose. When engineering colleges request physics departments to present an introductory course in atomic physics for large numbers of engineers, it seems evident that the introductory physics course will then have to be remodeled to provide the strongest possible background for this new objective.

Chemistry—Chemistry should include topics in inorganic, organic, and physical branches presented in condensed and general form. The initial study must prepare engineers to enter

advanced courses in chemistry and in its applications to such fields as properties of materials, metallurgy, fuels and combustion, corrosion, and industrial chemical processes. Hence, such subjects as rates and kinetics of chemical change, chemical equilibria, phase diagrams, solutions, electrochemistry, and colloids should be included. Careful coordination should also be effected between modern physics and chemistry. For studies beyond the usual freshman chemistry course it is felt that physical chemistry course it is felt that physical chemistry deserves the main emphasis.

F. The Engineering Sciences

An engineering science as defined here is a subject that involves largely the study of basic scientific principles as related to, and as related through, engineering problems and situations. Engineering science stems from two basic areas: mechanical phenomena of solids, liquids, and gases; and electrical phenomena. A common practice is to subdivide these into the following six engineering sciences:

1. Mechanics of solids (statics, dynamics, and strength or materials).
2. Fluid mechanics.
3. Thermodynamics
4. Transfer and rate mechanisms (heat, mass, and momentum transfer).
5. Electrical theory (fields, circuits, and electronics).
6. Nature and properties of materials (relating particle and aggregate structure to properties).

It is not necessary that this material be treated as separate courses. Experimentation should be encouraged to find the best way of achieving, with the available staff, the desired goal in a specific environment. It is not intended that the above shall be a complete list of the engineering sciences. *It may be anticipated that other engineering sciences will develop*; for example, information theory shows promise of contributing to measurement and control in all engineering fields.

Few existing curricula contain all six engineering sciences, despite wide agreement as to their basic desirability. It is evident that the engineer needs background in all of the six fields listed. Only after careful consideration and determination that the fundamental concepts are substantially covered in other studies at an equivalent mathematical level, should one of engineering sciences be omitted from a curriculum. Alternately, there may be some curricula or engineering programs for which sciences other than those listed must be chosen, for example, a life science or an earth science. *It should be possible to achieve the breadth, quality, and penetration desired by allotting about one fourth of the total program to the undergraduate study of engineering sciences.*

In the study of engineering science, full use should be made of the mathematics, physics, and chemistry described in the section on Basic Sciences, recognizing that some repetition is a normal pedagogical necessity, but that it can be most effective only when consciously and purposefully used. Perhaps nowhere else can the qualities of a scholarly engineering faculty be employed so effectively as in the presentation of the engineering sciences with an appropriate mathematical understanding.

The Committee is aware that many present curricula do not

contain adequate content in each of these fields. The Committee therefore stresses its position that the requirements for engineering sciences suggested above, as well as the requirements in basic sciences suggested herein, represent not only desirable goals, but the actual trend of future education for engineers. The suggested requirements are not intended to be taken as precise criteria for accreditation, although they are intended to be helpful in achieving higher standards for that purpose.

G. Engineering Analysis and Design

Education directed toward the creative and practical phases of economic design, involving analysis, synthesis, development, and engineering research is the most distinctive feature of engineering curricula. Such education intrinsically stems from the case method of approach, rather than from an orderly exploration of a given subject-matter field. Some experience in this "design" function should be carried in an integrated manner through each semester of the last two years and may be begun earlier if practicable. *Approximately one fourth of the total undergraduate program may be appropriately devoted to engineering analysis and design, including the necessary technological background*

Among various mechanisms for implementing the case method are theses, projects, group operations, competition between groups, the use of realistic or unsolved problems, examinations on unfamiliar subject matter, and the synthesizing of a new device rather than the analysis of an old one. These case studies go far beyond and are quite different from routine repetitive features of practical design, the use of handbooks, or the description of structures, equipment, or machines, including their construction, operation, and maintenance. Such engineering art is learned more effectively from field experience than from college study. *The capacity to design includes more than mere technical competence. It involves a willingness to attack a situation never seen or studied before and for which data are often incomplete; it also includes an acceptance of full responsibility for solving the problem on a professional basis.*

This portion of many engineering curricula demands close scrutiny and continuing active change. The major department sequences in many instances are dull and uninspiring, utilizing practices long outdated. These are areas in which newly developed concepts, analytical techniques, and measurements should be brought to bear. They should be taught by men who are making active contributions to engineering progress. For example, courses in Internal Combustion Engines are often largely descriptive in nature, and hence are essentially sub-professional. They can be vital experiences in which the principles and advanced analytical techniques of mechanics of solids and fluids, thermodynamics, and heat transfer are used effectively; the nature of combustion; friction, and materials are considered; and creative thought and imagination are brought to bear in producing an integrated system. To do this is a difficult and challenging job, but a very necessary one. These observations apply with equal force to such subjects as Power Plants, Highway Engineering, Electrical Machinery, Chemical Processing, Extractive Metallurgy, etc., etc. It is important again to stress the necessity of utilizing fully in such studies the

basic and engineering science training at the level which this report outlines.

H. *Engineering Laboratories*

The laboratory is the means of teaching the experimental method. It should give the student the opportunity to observe phenomena and seek explanations, to test theories and note contradictions, to devise experiments which will yield essential data, and to interpret results. Therefore, laboratories should be used where and only where these aims are being sought. The value of a set number of stereotyped experiments is questionable. The development of a smaller number of appropriate experimental problems by the students themselves under effective guidance will have much greater educational value.

The art of measurement—including analysis of accuracy, precision, and errors—and the appreciation of the degree of accuracy economically justified, together with some understanding of statistical methods, are essential elements of laboratory experience.

Laboratory reports, when restricted to a few per semester, present a major opportunity to develop skill in the written presentation of engineering information. Stereotyped reports are valueless in teaching the art of communication.

I. *Non-Departmental Engineering Courses*

Such courses as electrical engineering for non-electrical, heat engines for non-mechanics, etc., should emphasize fundamental ideas and principles and methods, rather than special machines or devices. *The most important engineering background of the professional engineer, apart from his major field, lies in the basic sciences and the engineering sciences.*

The study of engineering materials, including laboratory testing, is often scattered through several courses and can be coordinated to advantage. Increasingly, forward-looking engineers are searching the recent advances in solid-state theory and chemistry for an entirely new and fundamental scientific approach to the study of the behavior of materials. This field appears to be almost ready for engineering conquest, and its development will bear very close watching by engineering educators.

Graphical expression is both a form of communication and a means for analysis and synthesis. The extent to which it is successful for these purposes is a measure of its professional usefulness. Its value as a skill alone does not justify its inclusion in a curriculum. The emphasis should be on spatial visualization, experience in creative thinking, and the ability to convey ideas, especially by free-hand sketching, which is the normal mode of expression in the initial stages of creative work. Though the engineer may only supervise the preparation of the drawings required to execute his designs, he can hardly be expected to do this effectively unless he himself is thoroughly familiar with graphical communication.

Shop courses and all other courses emphasizing practical work that tend to displace engineering science in the curriculum should be scrutinized critically in the light of the instructional goals already discussed.

J. *Humanities and Social Studies*

The goals of engineering education already outlined require for their achievement adequate attention to subjects in the humanistic and social fields. In addition to technical knowledge and skill, the professional engineer needs to have some acquaintance with the subject matter of fields other than his own, with their influence upon the lives of men, and with their relationships to his own profession.

If the student is to be provided with a foundation upon which he may build a career of professional stature, his education must help him to seek his fullest development as an individual. This involves stimulating his imagination, instilling a respect for learning in all its forms, and creating an awareness of the great variety of ways in which man has sought order and meaning in the universe. College experience should facilitate the student's growth in ability to perceive significant relationships, to make intelligent value judgments, to express himself with ease, clarity, and good taste, and to develop the qualities of character and personality requisite for a successful career.

To the attainment of these objectives both the technological and the humanistic divisions of the curriculum should contribute as integral parts of one total program. It is a mistake to look upon technology alone as the productive component of the student's development and on the humanities as providing only the liberalizing elements in his pattern of growth. On the contrary, all of his courses of study, whatever their specific objectives in knowledge or skill, should be so designed and taught as to contribute toward the student's development as a truly educated man whose convictions, understandings, manner, and speech are intimately related components in the fibre of his life.

To serve most effectively their objective of giving breadth to the student's understanding of the world in which he lives and of awakening his interest in the great ideas that have evolved during man's struggle toward a better civilization, courses in the humanities and social studies should help the student to arrive at a satisfying personal philosophy rather than to provide him merely with immediately useful technical knowledge and skill.

Selection of Courses—The fields of humanities and social studies from which some courses must be selected include history, economics, and government, wherein knowledge is essential to competence as a citizen; and literature, sociology, philosophy, psychology, and fine arts, which afford means for broadening the engineer's intellectual outlook. The Committee has found no reason to disagree with the recommendations of previous ASEE Committees that *about one fifth of the curriculum should be devoted to humanistic and social studies.*

Such non-engineering courses as accounting, management, industrial finance, marketing, and personnel administration may well be valuable components of a particular curriculum, but being essentially technical in content, they do not adequately fulfill the main purpose of the program in humanities and social studies.

Motivating the student to learn on his own initiative is as much the aim in the humanities and social studies as it is in other parts of the curriculum. In the time available he cannot be expected to acquire a comprehensive knowledge of the sub-

ject matter of even one of the humanistic or social disciplines. He can, however, be given an understanding of the nature and function of some of the principal disciplines, together with an introduction to the methods of thinking likely to be most conducive to further growth in these fields within the life experience of the student. The courses should be designed to liberate him from provincialism, whether geographical, historical, or occupational, and to give him a sense of the satisfactions that he can gain later in life by adventuring more deeply into the areas of critical and creative thought represented in the humanities and social studies. His capacity to make sound qualitative judgments should be developed so that he may distinguish that which is good from that which is mediocre.

English—A word must be said here about English, which is both utilitarian and humanistic. Facility in expression, written and oral, is a professional necessity and an overall personal asset. Knowledge of literature and the ability to read with sympathetic understanding are parts of a liberal education. English, therefore, has one root planted in the humanistic portion of the curriculum, another in the technological. For developing skill in English usage sufficient for the professional engineer, sole dependence upon specified courses is not enough. Adequate motivation is essential; it can be attained only by active efforts on the part of all teachers to point out the economic and cultural rewards which will accrue to engineers who develop skill in the art of verbal communication. This requires personal counseling and sympathetic understanding of the student's pre-college cultural background, as well as insistence on the highest attainable standards of performance in written and oral work in the engineering courses.

K. Realization of Broad Social Objectives

To realize the overall objectives of the undergraduate program, a reasonable portion of the curriculum, such as a sequence of courses throughout the undergraduate years, should be allotted to formal courses in the humanities and social studies. But this, in itself, is obviously not enough. Members of the engineering faculty can make their own contributions to the general education of their students by precept and example, by their attitudes toward the work of colleagues in fields other than their own, by their support of the various extra-curricular activities that help so much in the maturing of an undergraduate, and by being themselves responsive to a broad range of cultural interests. An engineering faculty member who disparages the value of humanistic courses can hardly expect students who look to him as their ideal to enter upon such studies with enthusiasm.

Teachers on the liberal arts faculty should distinguish between the mission of developing scholars and conducting research in their own disciplines, on the one hand, and their obligation, on the other hand, to make available the knowledge and values that are significant for students majoring in other fields. This Committee believes that no effort to enhance the value of the humanities and social studies will yield greater returns than that devoted to bringing about a genuine community of interest, better understanding, and more meaningful cooperation between teachers of engineering and those in the liberal arts. The whole field of engineering education is the

joint enterprise of men in a variety of disciplines. For it to be effective and complete, they must respect and sustain each other.

L. Elective Courses

All too often present curricula leave no time for electives, either technical or humanistic. *The Committee believes that provision for electives should be made to an extent of about one tenth of the program exclusive of ROTC.* It also believes that there is an advantage in permitting some students to concentrate such elective study in science, while other students may choose electives largely in humanities and in social fields. The limiting of elective study to courses in the student's major engineering department is not consonant with the objectives being sought.

The Committee on Evaluation recognizes, as do most faculty members, that there is need for as much flexibility as possible within the framework of a given curriculum for each student to extend his own interests. Some choice may exist in the sequence of social and humanistic courses, in the later courses in mathematics and science, and in the departmental sequence of work in engineering analysis and design. However, it is primarily in elective courses that the student can best extend his interest toward his future professional activity. The objectives of engineering education are best satisfied when each student is given a free choice of options or elective courses, provided that the elected courses contribute to a planned objective.

M. Making Room for New Curricular Material

In this Report, several additions to curricula have been recommended without suggesting corresponding deletions. More emphasis on fundamental science, on engineering science, and on the broad humanistic and social areas has been recommended than is contained in most engineering curricula. This does not imply that the engineering student needs to be worked harder. Indeed there is considerable doubt as to whether there is any margin of student time left. Four possibilities for achieving these additional, important objectives are listed below. Each school, no doubt, will wish to choose its own methods, recognizing that those suggested are of varying degrees of practicability to each institution.

These four are as follows:

1. Raise the requirements for entrance.
This might entail:
 - a. More adequate high school preparation.
 - b. Higher selectivity.
2. Increase the effectiveness of instruction.
3. Eliminate some of the material now in the curriculum.
4. Extend the curriculum to more than four years.

Much has been written about high school preparation. Continuing encouragement should be given to high schools to raise their standards and to give appropriate training to college-bound students, including engineering students. However, it is doubtful whether engineering educators can realistically entertain serious hopes for substantial gains from this source over any short period of time. One ray of hope lies in the summer programs for high school science teachers that engineering schools, with cooperation of industry, have been

offering. Although higher selectivity would permit a more rapid rate of academic progress, it would decrease the number of applicants at the very time when national welfare calls for the reduction in the present shortage of engineers.

Increasing the effectiveness of instruction is a process more or less continuously under study by many faculties. Newer, simpler ways of looking at complicated phenomena and their analysis evolve continually in the minds of an alert faculty. Profound understanding of a topic is often accompanied by the ability to give a clear and simple statement. One contribution of our graduate schools to the development of undergraduate education should be a continuous simplification in methods of presentation of subject matter to undergraduates.

Elimination of Curricular Material—Elimination of material now in the curriculum, likewise, is an accepted practice in rapidly growing fields. Two kinds of material can well be looked at with a view toward possible elimination. Unduly repetitious material should be eliminated. Conscious repetition, carefully designed as a pedagogical instrument, may be used but not to the extent that it detracts seriously from student interest. Other areas due for close scrutiny, with a view toward possible elimination or reduction in time, are those courses having a high vocational or skill content and those primarily attempting to convey engineering art or practice. Some attention to engineering art and practice is necessary, but its high purpose is to illuminate the engineering science, analysis, or design, rather than to teach the art as engineering methodology.

A review of the evolution of engineering curricula over many years shows a trend toward increasing emphasis on the science underlying engineering at the expense of the study of engineering art for its own usefulness. This trend would appear sound for application in the present dilemma.

Thus, the Committee feels that the most promising possibilities of finding time for increased emphasis on fundamental science, engineering science, and humanistic or social studies are (1) elimination of some of the present curricular material and (2) increased effectiveness of instruction. If these criteria for elimination of material of a high vocational or skill content are applied rather forcefully by engineering faculties, it is felt that opportunity will be found within the usual time limits to increase basic studies as indicated in this Report. This will not be achieved, however, by repair of patchwork curricula. It requires complete reconstruction of curricula.

The Committee, after careful consideration, takes no position with regard to the length of the program. It believes, however, that further experimentation is called for in all four of the means suggested for introducing new curricular material.

IV. EVOLUTION OF ENGINEERING CURRICULA

The great changes in physics and chemistry over the past thirty years and the equally great advances in engineering practice do not seem to have produced an equivalent counterpart in a reorganization of engineering curricula. A group of industrial advisors to the Committee has pointed out that the problems in production and manufacturing are now demanding greater and greater scientific background for engineers. As one example, emphasis was placed upon automation as a current problem of the machine designer. The need for such instruction is critical in certain industries, and several of these offer such courses to their personnel. If this is generally true, engineering education may be a decade late in giving emphasis to electronics in the curriculum of mechanical engineering or in teaching applied electronics as part of machine design.

A. *Unchanging Factors in Curriculum Design*

It is relatively easy to look backward and recognize changes; it is more difficult to visualize what lies ahead. After facing many questions regarding the future of engineering practice, one is likely to conclude that the teaching of practice, as it exists today, will always be of limited use because the graduate is certain to find practice changing from year to year. And, as a matter of fact, the engineering art taught in colleges will normally reflect practice that is already obsolete in part, since the teacher's knowledge of practice becomes rapidly outdated.

But fortunately, some things do not change. Reactions, stresses, and deflections will still occur, and they will have to be calculated. Electrical currents and fields will follow unchanging laws. Energy transformation, thermodynamics, and heat flow will be as important to the next generation of engineers as to the present one. Solids, fluids, and gases will continue to be handled, and their dynamics and chemical behavior will have to be understood. The special properties of materials as dependent upon their internal structure will be even more important to engineers a generation hence than they are today. These studies encompass the solid, unshifting foundation of engineering science upon which the engineering curriculum can be built with assurance and conviction.

B. *Attitudes of Engineering Faculties*

The problem that faced the Committee on Evaluation of Engineering Education soon after its organization was to think through the implications of the steadily increasing importance of the engineering sciences upon curriculum design and upon faculty, students, and employer relations. The questions to be answered were of the following nature. Would faculties believe that much stronger emphasis upon the engineering sciences and the basic sciences will produce only research men? Would the employer be pleased with graduates of such programs or would he prefer men able to earn their salary immediately upon graduation without special job training? Could students undertake a more scientific program without excessive failures?

Not knowing the answer to these questions, the Committee suggested in its Preliminary Report the concept of bifurcation as a possible means of transition from the present curricula,

which are largely of the general professional category, to the strong scientifically oriented curricula that it visualized as being required for an unknown, but in no sense negligible, percentage of future graduates. As defined in the Preliminary Report, the scientifically oriented curriculum included increased emphasis upon mathematics and physical science, the engineering sciences as previously described, and a two-year sequence of courses in engineering analysis, design, or the study of engineering systems.

The discussions of the Preliminary Report which were forwarded to the Committee by the colleges of engineering established a reasonably clear viewpoint. This consensus of engineering faculties consisted of three parts: (1) a strong support for higher standards of accreditation for engineering education but not for designation of especially meritorious curricula, (2) a nearly universal institutional reaction that engineering curricula should not be subdivided into two functional stems but a recognition of the usefulness of functional variation at the top, and (3) a growing desire for a deepening and broadening of basic science content throughout all engineering curricula.

C. Viewpoint of Employers

After receiving this expression of attitudes from the engineering institutions the Committee determined to learn something of the viewpoint of employers. At a meeting in Atlanta, Georgia in February, 1954, seven of the largest employers of engineers were invited to advise the Committee. These organizations employ all types of engineers in all functions from research to sales and construction. In fact, most of the organizations represented employ only a small fraction of their engineers in research, development, and design. On the average less than twenty-five per cent of their engineers work in these fields. One company has most of its engineers employed in operation and another in manufacturing. A third has one of the largest construction organizations in the country. Several employ nearly one half of their engineers in sales. Nevertheless, the industrial representatives who were present concluded that they would prefer nearly all of their engineers to be trained in scientifically oriented curricula.

The industrialists emphasized that their sales, manufacturing, operation, and maintenance engineers need strong scientific backgrounds just as much as do their research and development engineers and their designers. They were unwilling to sacrifice courses in engineering sciences to provide time for the study of technology or administration at the prebaccalaureate level, since they believe that these can be obtained under company sponsorship when needed.

Initially the industrial advisers to the Committee represented only large employers. Therefore, the Committee requested one of the companies to make a survey of a number of smaller organizations at the operating and manufacturing level. The returns indicated no criticism of the technical competence of engineers but raised questions concerning (1) the adequacy of their background in basic science, engineering science, and humanistic fields and (2) concerning their capacity for effective communication. This reaction with regard to the inadequacy of basic science and cultural background was essentially unanimous.

D. Abilities of Engineering Students

The Committee on Evaluation has also given consideration to the question whether a stronger emphasis upon basic science and engineering science would lead to increased failures in completing engineering curricula. Some who have experimented in this direction give assurance that this common assumption is not necessarily true. The best authority to the effect that engineers can handle additional work in basic science and engineering science without undue difficulty lies in the results of national tests. These indicate that at both the undergraduate and the graduate levels, engineering students show the same high level of mental ability as students of the physical sciences. It seems reasonable to conclude, therefore, that the principal groups of engineering students will prove able to complete whatever type of curriculum the profession of engineering considers necessary preparation for its prospective members.

E. Opportunity for Scientifically Oriented Curricula

The consideration of curricula cannot proceed wholly on a philosophical or qualitative basis but must eventually be approached quantitatively in semester hours or at least in terms of fractional percentages of the total program. The Committee on Evaluation, in order to clarify for itself the practicability of its suggestion that curricula of the usual type can be designed with an enhanced scientific orientation, has developed for consideration the broad outline of scientifically oriented curricula. It intends this skeleton curriculum to be considered as suggestive rather than restrictive. The great need of engineering education at this time is for experimentation with, rather than standardization of, curricula.

In defining an engineering curriculum the Committee on Evaluation has first indicated the need for *mathematics through differential equations*; however, another application of calculus, such as mathematical statistics and probability, might fit more effectively into industrial or sanitary engineering. Nevertheless, for many existing curricula this means at least one additional course in mathematics. The recommendation that *physics should be extended through an introduction to modern physics* will require more than the usual eight semester hours of sophomore physics, even though some time may be saved by elimination of problems involving semi-engineering applications. There is a growing belief that *some acquaintance with organic chemistry and a working knowledge of physical chemistry is essential to all engineers* and that this objective can not be accomplished within the usual course in freshman chemistry. For most curricula these changes in mathematics, physics, and chemistry would probably require a total of at least six semester hours of additional study.

The second major factor in the original definition of scientifically oriented curricula included nine engineering sciences in sufficient strength to justify their separate listing. *These have now been regrouped into six engineering sciences*: (1) mechanics of solids (statics, dynamics, and strength of materials), (2) fluid mechanics, (3) thermodynamics, (4) transfer and rate mechanisms (heat, mass, and momentum transfer), (5) electrical theory (fields, circuits, and electronics), (6) nature and properties of materials (relating particle and aggregate structure to properties). *These titles should be regarded as generic and broadly defin-*

itive rather than as representative of courses now being offered. In regrouping the engineering sciences into six categories, the Committee made no reduction into the minimum time considered appropriate for their study, which represents one quarter of the engineering curriculum.

The third major element in the definition of an engineering curriculum is that it must contain an integrated sequential study. By this is meant that mathematics and the basic science shall be used proficiently in the courses in engineering science and that the latter, in turn, shall be used proficiently in engineering analysis, in the study of engineering systems, and in the preparation for creative design work. For the scientifically oriented approach it seems desirable that analysis, synthesis, and creative design cover four successive semesters at an intensity to be represented by five or six semester hours per semester.

In addition to basic science, engineering science, and engineering analysis and design, allowance may be made for a minimum three-credit-hour humanistic or social science course each semester for at least seven or eight semesters and also for a small amount of required technology. The general outline of any scientifically oriented curriculum may therefore be described in five blocks of courses under the following headings: humanistic and social studies, mathematics and basic sciences, engineering sciences, engineering analysis and design, and electives.

It will be noted that the fractions given do not total exactly one-hundred per cent. Hence, it should be evident that the Committee does not desire this suggested distribution of emphasis to be restrictive. There will be many reasons for variations among institutions and among departments of a single institution. *Experimentation is strongly encouraged.*

Summary of Time Distribution for Scientifically Oriented Engineering Curricula	
(1) Humanistic and Social Studies (Pages 39-41)	About one fifth
(2) Mathematics and Basic Sciences (about equal weight) (Pages 36-37)	About one fourth
(3) Engineering Sciences (Pages 37)	About one fourth
(4) Sequence of Engineering Analysis, Design, and Engineering Systems, Including the Necessary Technological Background (Pages 37-39)	About one fourth
(5) Options or Electives in (a) Humanistic and Social Studies, (b) Basic Science, (c) Engineering Science, (d) Research or Thesis, (e) Engineering Analysis and Design, (f) Management (Page 41)	About one tenth

In the above table, items (1) through (3) consume about seven tenths of the curriculum. They define an area of common orientation which the Committee regards as essential to a unity of understanding by students in different engineering fields. There is no reason why such unified understanding can not be achieved by somewhat different courses, with different instructors. It will not be achieved, however, if technology is substituted for basic and engineering science or if courses with names from fields of engineering science are presented merely

as a necessary sideline to the objective of teaching current practice.

The Committee's interest in the curriculum outline above is centered in: (1) the indication that the concept of four-year curricula with scientific orientation is practical (2) the indication that considerably more than the usual "common freshman year" is an evolutionary result that could accompany scientific orientation of curricula if desired, (3) the opportunity presented by elective study for meeting the interest orientation of students and the functional needs of engineers engaged in research and design as well as in management and construction.

V. SPECIAL FACTORS THE INFLUENCE UNDERGRADUATE EDUCATIONAL ACHIEVEMENT

A. Student Selection and Advanced Standing

It is recommended that high school students interested in engineering be encouraged to prepare themselves adequately for engineering work in high school by developing proficiency in the use of English and mathematics and by gaining an understanding of science, particularly physics and chemistry. A most effective way of so encouraging these students is to make proper adjustment in the work required of them in engineering schools. This may be done by allowing college credit for previous work, or, if this is undesirable, by making the credit hours required for graduation flexible and dependent upon the preparation and skills of the entering student. A student should not be required to repeat work in college if he is adequately prepared by work already covered or by proficiency previously acquired in high school or elsewhere; instead he should be allowed to proceed into more advanced work. When so excused from taking a specific course on the basis of previously developed proficiency, he should not be required to substitute other work not demanded of other students, for this requirement always discourages students from presenting advanced work for entrance. *However, proficiency should be determined by examination and should not be assumed because of the acquisition of high school units beyond those required normally for admission.*

Requirements for admission to an accredited engineering curriculum must of necessity be rather rigorous to insure adequate capability of the student to pursue engineering studies in an orderly and effective manner. The Committee, therefore, recommends the following minimum requirements for admission:

1. Graduation from an accredited secondary school, or demonstrations of equivalent education.
2. Demonstrated capacity for satisfactory achievement in engineering.

It should be recognized that the minimum requirements listed above impose great responsibility upon directors of admission for proper selection of students for engineering colleges, especially when the availability of required courses in the various high schools is taken into consideration. Such students should normally accumulate at least three units of English, four of mathematics, and at least one unit of physical science if they are to make satisfactory progress in engineering schools

whose curricula are organized on a high professional level. Furthermore, unless suitable screening techniques are applied, such students should stand in the upper quarter of the overall integrated group of high school graduates. It is suggested that pursuit of vocational courses should be discouraged as preparation for engineering and that not more than two of the sixteen units for entrance should be considered from drawing, shop, or other vocational work. Additional background in mathematics, science, and humanistic and social courses is of far greater benefit to the student.

The Committee also recommends that colleges should:

1. State their requirements for admission clearly.
2. Elect to admit students with deficiencies only when there is strong evidence to indicate probable success in engineering and always state clearly what those deficiencies are and how they may be removed.
3. Maintain records of criteria used to determine admission.
4. Use such records to improve the screening process.

Students transferring from accredited junior colleges, liberal arts colleges, or other engineering colleges should be admitted on a provisional basis; the final transfer of their credits should be delayed until their subsequent records indicate maintenance of the achievement level required for graduation. A realistic evaluation of credits presented for advanced standing should be made on the basis of course content or a proficiency examination rather than on an inflexible basis of equivalent credit hours.

B. High School-College Articulation

As preparation for engineering education there is no substitute for scholarly levels of instruction in high school with adequate emphasis upon developing both interest and reasonable proficiency in mathematics, English, physics, and chemistry. The Committee on Evaluation believes that a great deal can be done to improve the scholarly quality of education offered in the high schools. This can best be accomplished by developing close working-relationships between engineering colleges, high schools, and ECPD guidance committees at the local level. The ECPD Committee on Guidance should be encouraged to extend its activities in this direction. Some engineering colleges have developed conferences and educational programs, jointly participated in by high school and college teachers. Several industries have provided the financial support for such education programs. These programs can be highly effective in giving high school teachers an insight into the nature of the scientific and mathematical preparation which is needed by students who plan to study science or engineering in college.

In order to encourage high school-college articulation, it is recommended that a study be undertaken by ASEE in cooperation with professional and industrial groups and societies representing mathematics and the pure sciences for the following purposes:

1. To determine specific techniques for identifying, encouraging, and developing those high school students who have aptitudes for engineering or science.
2. To determine methods for developing adequate study habits and a suitable level of performance in reading ability for those students planning to attend college.

3. To develop specific techniques of reaching high school faculties and administrators in order to enlist their cooperation in a constructive program to improve the quality of high school preparation particularly in mathematics, physics, chemistry, and English.

4. To determine, at each university engaged in teacher training and having a college of engineering, ways of providing advance study as part of high school teacher education that would make such teachers more proficient instructors in the subjects necessary for admission to engineering.

5. To develop specific techniques for presenting these problems and their possible solutions to high school administrators, teachers, and the general public.

C. Providing Opportunities for Gifted Students

Leading engineering educators have long felt that the standardization of engineering curricula in the United States has provided too little opportunity for outstanding students with creative talents to develop these capacities at the greatest possible rate. Most courses are organized to proceed at a rate that can be followed by the average and, commonly, by the below-average student. At some place in the undergraduate program there should be an opportunity to break this "lock step" and permit the student full play of his intellectual and creative powers.

The Committee is aware of three possible methods for providing such opportunities. The first is the special curriculum, designed both in content and in method of administration to challenge adequately the exceptional group at the top of a class. The second method is that of permitting the exceptionally able student to elect his program widely with due precautions against excessive specialization; to carry as heavy an academic load as experience indicates he can handle; and, in general, to let him build out of the courses that may be available, including in special cases appropriate graduate courses, a program that stimulates and challenges him. The third method, and the one that philosophically has the greatest appeal, is that of giving the student a great degree of personal freedom to study individually under general supervision and guidance in whatever way appeals to him as being most effective in his individual case. Combined with this, of course, must be a rather infrequent but very searching examination designed to provide an overall measure of his accomplishment and to test his level of understanding in a broader and yet more penetrating way than the usual term examination.

The first and second methods—that is, the special curriculum for a gifted group and the individually elected curriculum, respectively—are in regular practice at various institutions in the country. Any adviser, if he is given freedom to adjust the curriculum, can adopt the second method whenever he recognizes among his students one who is capable of benefiting from such a program. While the results of such procedures are extremely difficult to measure with any degree of certainty, the evidence is not unfavorable.

In the case of the third type of program, however, experience in engineering in this country has not been conspicuously convincing. One difficulty is that, given a large measure of freedom as to place, method, and program of study with only

the most general sort of restraint in the form of comprehensive examinations at the end of one- or two-year periods, very few students will absent themselves from rather regular classroom exercises if these are handled in a reasonably interesting and inspiring manner. Class exercises are an exceedingly effective way of acquiring basic, scientific disciplines. Other students who take seriously the admonition to study independently have often found that they lacked the necessary self-discipline to achieve the same intensity of intellectual effort and actual accomplishment as that achieved by the regular students. This has sometimes been revealed disconcertingly when such a student has later been faced with the searching doctoral examination in which demonstrations of relatively elementary ideas, but at a profound level, have been required. The student who has enjoyed complete freedom under general guidance has often failed to acquire the degree of exacting mastery of basic principles that is expected.

The brilliant student who becomes the personal protege of a wise and able professor, however, may attain extraordinary achievement under a free program. This rather rare student is obviously an exception to all rules, and the perceptive and wise faculty member will break many rules in order to allow him to develop his own initiative and ideas. Such students will set their own courses in life, faculty members notwithstanding, and they do not constitute the problem being considered here. The adequate social development of such individuals, however, may be a serious problem. Intellectual development and social development are interrelated; hence, one cannot be accelerated and the other ignored.

It is, therefore, the rather select group found in the top ten per cent of a good class with whom faculties should be more concerned. There are, of course, many ways in which the monotony and tedium of the highly organized classroom course can be relieved for these students. The privilege of joining faculty societies of scholars should provide exhilarating motivation in this direction. Such students should be given individual encouragement that will help stimulate them to something beyond the ordinary performance. In the United States there is a great need for continued experimentation in the search for the solution that apparently is still to be found for this important problem. The European solution, although excellent in its natural setting, has not proved susceptible to direct transplantation to this country. The strongest encouragement should be given to those teachers and administrators who would like to experiment in increasing the responsibility of gifted students for their own education.

VI. FOREIGN STUDENTS

The foreign student brings both assets and problems to an engineering school in a ratio that can be greatly influenced by wise administration. Also, our world obligations place a responsibility upon us to make the foreign student's experience valuable to him in terms of the problems and opportunities he faces when he returns home.

Credentials of foreign universities are often difficult, if not impossible, to evaluate in terms of American standards of admission. Hence, internal placement examinations are sometimes necessary. There are difficulties the foreign student expe-

riences in adjusting himself to the university in terms of language and cultural tradition. Insistence upon reasonable facility in conversational English is, therefore, essential. There may also be serious financial problems.

The foreign student who is well prepared is likely to be well advanced in theory but inexperienced in laboratory procedures. Sound programs for such as student will recognize these facts.

A. ROTC Credit

The Engineering Colleges recognize their obligations to the nation to train through the mechanism of ROTC a supply of future officers for the Armed Forces. It is believed that this should be accomplished without compromise with the basic educational concept developed in this Report.

The Military Affairs Committee of the ASEE, at the request of the Committee on Evaluation of Engineering Education, made a survey to determine the credit being allowed currently for advanced ROTC courses and what credit was considered reasonable. The replies made it clear that the majority of engineering colleges do not recognize advanced ROTC as an appropriate substitute for engineering courses. However, an average of about six credit hours is being accepted as a substitute for humanistic and social studies. More than fifty per cent of the engineering colleges do not allow credit for advanced ROTC as a substitute for engineering courses, and about twenty-five per cent do not allow credit toward humanistic and social science courses.

The Committee on Evaluation recommends that no credit be allowed for advanced ROTC courses as a substitute for engineering courses. The Committee also looks with apprehension upon appreciable substitution of ROTC credit for humanistic and social studies. Although the context of certain ROTC courses may involve geography and government, fundamental differences exist between these courses and those offered in the humanities and social sciences.

The major differences in course objectives, course organization, and qualification of instructors are valid reasons why the ROTC courses generally cannot contribute in a major way to the professional and liberal education of an engineer as do the other courses in the curricula. Ideally, no substitution of ROTC credit should be allowed either for engineering courses or for those in the humanities and social studies. *As a practical matter it is urged that substitution of advanced ROTC credit for humanistic and social studies alone should not exceed one quarter of the total credit allotted to this area.* Experiences in a wide range of institutions demonstrate that the advantages to the student of ROTC training are sufficient to attract his enrollment without diluting his professional and cultural education through granting academic credit for ROTC beyond the amount proposed.

VII. GRADUATE STUDY IN ENGINEERING

The growth of graduate study in engineering in the past two or three decades has been remarkable. Both statistically, and in the minds of those concerned with engineering education, graduate study has become an element of such major impor-

tance that it necessitates serious attention in any evaluation of engineering education.

The need for post-baccalaureate study by those who are to advance our highly complex technology is generally recognized. The four-year program, even with increased scientific emphasis, simply cannot provide the depth and breadth of scientific foundation and the background for creative thinking in design which are needed. *The need for graduate education varies with the rate of advance in the use of science characterizing various fields of engineering; it is greatest in those fields in which this rate is most rapid or to which science can contribute most directly.* Industry places a substantial value upon graduate education, as indicated by recruiting efforts, salaries, and advancement to positions of high degrees of responsibility. Furthermore, as is implicit in this Report, engineering education must be based more and more on a profound knowledge of the basic sciences and so will require that an increasing proportion of its teachers will have the benefit of advanced graduate education. It is obvious, therefore, that educational institutions with *adequate* resources to support good graduate work in engineering have not only an opportunity but also an obligation to attract and develop as many well qualified graduate students as possible. Those educational institutions which operate solely on the undergraduate level have also an obligation to participate by preparing and encouraging their students to take graduate work elsewhere. Many small schools have made impressive records in furthering graduate education in this way. Even institutions having well developed graduate programs should encourage their better students to enroll in other similarly qualified institutions for graduate study because of the educational advantages to the student of new scholastic environments and different personalities among their instructors.

It is traditional for institutions of higher learning to serve two ends: disseminating and extending learning—that is, education and research. It is common to distinguish three separate yet closely related activities: undergraduate education, graduate education, and fundamental research. When these are maintained in adequate balance and properly correlated, each can enormously strengthen the other two. One kind of correlation that is very effective is attained by having faculty members who wish to engage in all three activities.

A. Objectives of Graduate Study

Although one conception of the purpose of graduate study is that of increased specialization in a narrow field, the Committee feels that a broader conception, developed as discussed below, is more significant. For example, the topics in organic and physical chemistry or in solid state and nuclear physics, which seem so essential to one “specialized” graduate program in engineering, will be almost exactly duplicated in many others. Graduate study in engineering thus has a broad common base in science and mathematics. Such concentration as may be desirable, for example on a thesis, should be undertaken with the objective of developing breadth of understanding and capacity to solve difficult problems. Naturally the student who studies intensively in one particular field possesses a ready skill in this special area which may have immediate utility. Such facility, however, has only a temporary value without

the overall intellectual growth through which the individual can master new techniques in any of numerous fields. *The acquisition of techniques is, therefore, incidental in graduate educational experience, the deepening of insight and understanding, and the development of the stronger intellectual and scientific foundations that are required for real mastery of the field involved.*

Hence, the objectives of graduate study in engineering are the development of (1) a more general and fundamental understanding, not only the sciences specifically underlying a particular field, but also of those underlying related fields; (2) more general and more powerful methods of analysis; (3) capacity to read with understanding the advanced work, classic and contemporary, through which the field is advancing; and (4) courage, imagination, and technical capacity to make new advances and to know the methods, as well as the failures and successes, involved in such advances.

A recognized objective which is being implemented at a few institutions is that of continuance of general education outside the fields of engineering and science at a serious and mature level. This is particularly important for those who expect to become engineering teachers. The growing broad responsibilities of all engineers further justify increasing attention to this objective. Culture can, of course, be acquired by penetrating self-study in a variety of fields or assimilated by close association with scholars. Its acquisition is seldom neglected by those who are regarded as leaders in their own fields, nor can it be by those who would live a complete life.

B. Requirements for a Strong Graduate Program

The essential requirements for a strong graduate program are few, simple to state, but difficult to achieve. They are: (1) a specially qualified faculty, (2) students of superior ability, and (3) adequate administrative and financial support. Without each of these requirements, graduate work worthy of the name is impossible. Given these characteristics, such elements as curriculum, requirements for degrees, laboratory facilities, sustaining research programs, library, student housing, associations with the leading national and international centers in the field, and intercourse with related and underlying fields of learning and research can be expected to evolve. Each of these three requirements is examined in some detail below.

The Graduate Faculty—To an even greater extent than in undergraduate education, an outstanding faculty is the single most important requisite for successful graduate work. As emphasized in the section on the Selection and Development of an Engineering Faculty any good teacher must have drive, enthusiasm, judgment, and a sincere interest in the development of men. Although it is not possible to draw up a set of rigid specifications for a graduate faculty, the following characteristics are among those common to many outstanding graduate teachers in engineering:

1. A creative talent and receptiveness to new ideas which manifest themselves in the constructive use of new knowledge.
2. A fundamental and critical understanding of one or more fields of engineering.
3. An ability to relate knowledge and experience in one field to a total concept involving many fields of endeavor.
4. A high intellectual capacity and an insatiable desire to

learn and to understand.

5. A profound understanding of the basic sciences, including mathematics, as they relate to engineering.

The full development of the qualities listed above means that the successful graduate faculty member is either actively contributing to the frontiers of knowledge or is engaged in applying new knowledge successfully to the solution of challenging situations. The graduate faculty member should enjoy teaching. He must desire to transmit his ever growing knowledge and understanding and urge for intellectual growth to young people. In his teaching, however, he should deal with students as colleagues, rather than as pupils, whether in the classroom, office, or laboratory. This obligation to the student cannot be fulfilled properly unless the teacher is doing creative work.

The strong faculty is composed of a group of men of diverse talents and interests who are dedicated to the overall objective of providing the stimulation and environment for the professional growth of themselves and their students. This is desirable, but the nature of the tasks and attitudes in teaching advanced subjects must necessarily be somewhat different from those in undergraduate teaching.

The graduate faculty deals with a student body comprising a selected group of the best students who have completed an undergraduate course of study and have indicated a keen interest in preparing themselves for high-level professional work. While many such students are interested in research, development, and creative design, the rapid growth of technology is also creating demands for men trained at the graduate level to employ greater understanding in the solution of problems in the area of production, management, etc. There is good evidence that the best graduate education for these differing functions in engineering is one that will develop the intellectual capacity of the individual rather than high specialization toward a given functional objective.

Faculty-Student Relations—Because of the close associations that are typical of graduate work, graduate teachers have an opportunity to know their students well and to provide the individual inspiration and leadership that is an essential part of the graduate environment. Moreover, this relationship properly used insures that the student is impelled to take the initiative and to work on his own or as a full-fledged partner without undue assistance. *Nevertheless, the wise teacher recognizes the great transition involved in movement from undergraduate to graduate study and accepts responsibility for exerting the skillful leadership needed to bring the student quickly to the stage of independent study.*

Though interested in developing student competence and enthusiasm in his own field, the good graduate teacher stimulates student interest in many fields. Such teachers are on the alert to detect evidence of imaginative and creative thought and to give encouragement and support necessary to bring such ideas to full development.

The Graduate Student—A faculty having the requisite abilities for conducting a graduate program will insist that the graduate student body be intellectually and temperamentally qualified for graduate level work. First-rate graduate work makes substantially greater intellectual demands than undergraduate work. It also demands more in imagination, in

self-reliance, and in capacity for independent work under less specific guidance.

Because of the greater dependence of success upon centered interest and intellectual outlook and character, the selection of graduate students must depend upon individual appraisal. Certain general guides are, however, widely used. Not all of those who receive a baccalaureate degree are normally regarded as qualified for graduate work. In general, experience indicates rather marked correlation between a student's standing relative to his undergraduate classmates and his subsequent performance in graduate work. A very large percentage of the qualified engineering graduate students will have been top-quarter undergraduates in their field, though this rough criterion will vary somewhat with the rigor of the school and with individual student development. The majority of good doctoral prospects will lie within a much narrower fraction, perhaps the top tenth or less, but those students who make top grades by rote learning in an undergraduate program may still be poor prospects as graduate students. *The attitude that most students deserve a chance at graduate study is inimical to the intellectual objectives to be achieved and may be damaging in its effect upon those who are qualified for graduate study as well as those who are not.*

Selection of graduate students is a relatively straightforward process for a faculty having high intellectual standards and the courage of conviction regarding these standards. Good students can be selected, however, only after they apply for graduate study. In order to encourage the best students toward graduate work, the great need is to provide the undergraduate student, preferably at the junior level, with adequate information about graduate opportunities and requirements and also about the advantages or disadvantages of graduate study as a means of attaining professional stature. Our best qualified undergraduate students repeatedly undergo a skilled, persuasive presentation of the opportunities available to them in immediate employment. They should have an equal opportunity to know and to examine carefully the available alternatives.

Stipends for graduate students should be increased to a level more competitive with advancing engineering salaries and should reflect the fact that present-day graduate students often have dependents. Employers of engineers must understand that they have a very great stake in increasing the number of graduate students, even though they may lose in the number of immediate employees, and even at the cost of competitive graduate or research fellowships that only they can provide.

Administrative and Financial Support—No graduate school can be successful without the full support of the administrative officers. To be able to provide such support, the administration must have full knowledge of the special problems created by the existence of a graduate school. As at the undergraduate level, the administration has the responsibility to build a strong faculty, to encourage the attraction and selection of qualified students, to provide adequate facilities, and to create a favorable intellectual climate.

The job of building a strong graduate faculty composed of men with the necessary attributes and competencies is difficult, never ending, but not impossible. *A competitive salary scale for a graduate faculty is imperative. Creative talent is always in greater demand than supply. In addition, proper facilities must be provided and a favorable environment developed so that men may pursue*

those activities of research, development, and creative design which mark the life of the graduate school teacher. Such facilities include laboratories, adequately equipped; the various service facilities; and an adequate library. Facilities for students, including desks and laboratory space, and housing where necessary, must be provided.

Last and perhaps most difficult of all, the administration must itself have the spirit of dedication to the advancement of knowledge without which no graduate school can become really great. Such a spirit is reflected in an ability to recognize:

1. That in evaluating teaching loads account must be taken of the greater time required for preparation of graduate subjects. Graduate courses should be under constant change with new knowledge being fed in as soon as it becomes available.

2. That research, development, and creative design, which demand a major portion of the professor's time, are part and parcel of the graduate teaching job.

3. That the supervision of thesis research is time consuming even though it is also a rewarding educational duty.

4. That the best graduate programs are based upon the strength of particular faculty members rather than upon any fixed curriculum content.

5. That a strong graduate engineering program requires equally strong independent programs in the basic sciences.

To meet the above responsibilities involves an annual cost per student from two to ten times as great as that required to educate an undergraduate. No school of engineering should consider instituting a graduate program unless it is willing and able to provide the additional funds required.

Policies that permit full opportunity for the professional growth of individual faculty members must be such as to meet the special problems that arise in connection with sponsored research projects, consultation for industry and government, and participation in community affairs. These activities in proper balance provide opportunity for continuing development of the faculty.

In the last decade the amount of sponsored research carried on by engineering colleges has grown enormously. Sponsored research programs properly conceived and carried out can be great assets to both graduate and undergraduate schools. They provide a means of professional development for staff members. However, only when tied closely into the graduate school program will they provide opportunity for graduate students to deal with real and challenging problems as a part of their education. A criterion of acceptability for each project is that competent faculty members actively desire to work on it. However, growth in the size of the projects may so consume the time and energies of the staff that their contribution to education diminishes, particularly if the work becomes more routine and less challenging.

The administration is responsible for the establishment and control of such programs, for retaining proper balance between the sponsored research commitments and the other parts of the educational program of the institution, and for taking whatever steps are necessary to insure that services performed on projects provide opportunity for professional growth for the faculty and the graduate students.

C. General Character of Graduate Programs

Though graduate study in engineering may appear to be but an extension of academic preparation for the more scientific phases of engineering practice, it should represent a considerable advance beyond undergraduate study in attitudes as well as in subject matter. Undergraduate education, even when developed on sound scientific principles, must be based on simplified concepts if it is to be understood by undergraduates and if it is to serve as an introduction to practical engineering design. The more advanced concepts are, of necessity, intelligible only on a considerably higher mathematical level, and yet it is these advanced concepts that form the basis of our most penetrating knowledge of physical phenomena.

*Comparison with Undergraduate and Specialized Programs—*The creation of new products, industries, structures, or operations will involve not only scientific analysis of a higher order, but also new concepts of synthesis or design. Training in these categories is limited in undergraduate curricula, not only because students must master a minimum amount of knowledge before they are prepared to extend or apply it, but also because individual instruction on this level is too costly in view of the number of students involved.

Furthermore, genius is not well nurtured by the fixed curricula so characteristically prevalent today in undergraduate fields. Hence, graduate study should be flexible and custom tailored to suite the individual. This does not involve unrestricted selection of electives, for universities take seriously their responsibilities in awarding graduate degrees and rightly approve only those subjects that contribute substantially to the major and minor fields. In engineering one of the required studies is almost invariably advanced mathematics, for the graduate student requires additional mathematics to conduct advanced work and to convey his scientific explanations to others. *On the level of the master's degree anything less than a full-year course in mathematics beyond elementary differential equations appears to be inadequate for effective understanding and use of the scientific principles on which advanced work in engineering will almost inevitably be based.* The doctoral level demands at least an additional year of mathematics. As stated previously, few engineering courses are taught in a manner to make significant contributions to the student's knowledge of mathematics, nor is time available for this purpose.

*Student Initiative and Responsibility—*Initiative and willingness to accept responsibility become most evident when graduate students undertake the research for master's theses, but more especially for the doctoral dissertations. Such labors usually require (1) an intimate knowledge of related scientific and mathematical principles, (2) experience in collecting relevant and discarding irrelevant information from many sources, (3) the imagination and ability to devise a new and logical method of attack, (4) the perseverance to complete the analysis, (5) the planning and performance of experiments to check the analysis, (6) the willingness to digest these results, and (7) the exercise of judgment in drawing valid conclusions. An appropriate thesis offers exceptional opportunity for additional educational experience and development of the student as well as a test of the degree of their achievement.

Importance of Science—A comprehensive knowledge of mathematics *alone* has little practical utility for an engineer unless it is employed to effect an equally profound understanding of those physical, biological, or engineering sciences which are the necessary background for creative design. All engineers must deal with materials, and they need to understand the behavior of materials when subjected to varying service conditions in mechanical, electrical, chemical, or nuclear fields. Recent advances in solid-state physics indicate that knowledge of materials on an atomic and a microscopic level is required for an understanding of macroscopic or phenomenological behavior. Advanced training in science is thus most important for the graduate engineering student. It matters little whether this science is offered in special courses or integrated into others. It must be covered and can appropriately grow into the proportions of a full-fledged minor, or become an integrated portion of the major field.

Nature and Important of Research—A young engineer who has an interest in research or development will find his progress more rapid in his chosen field if he can avail himself of the opportunity for the training in research which exists in any good university. The importance of this aspect of graduate study hinges on the exhilarating experience of penetrating deeply enough into some unexplored problem to uncover new truths, and to do this in association with one who has already proven himself a master of the field. The inspiration so derived is essential for a beginner in research, for he must not only learn to circumvent failures but gain the confidence to tackle new and difficult problems as they arise in engineering practice.

D. Graduate Housing

In graduate even more than in undergraduate work there are important intangible benefits of association with other students and faculty provided by congenial group living in university graduate housing. The graduate student, much more than the undergraduate student, works in an atmosphere of independent individual study and needs for his best growth and development continuous interchange of ideas with and stimulation from students of equivalent intellectual level. *Perhaps no other experience is so likely to develop the inner desire to be truly literate and alive in fields far removed from one's own specialty as is a period of congenial residential association with other graduate students.* For married students the housing problem takes on a somewhat different form, but the essential issues remain unchanged. Administrative effort to provide housing should be just as vigorous for graduate as for undergraduate students.

E. Service Programs for Industry and Government

Though it is generally agreed that graduate study in engineering has become indispensable to prepare men properly so that they may contribute effectively at advanced professional levels, only about one eighth of engineering graduates actually acquire graduate degrees. Industry and government have recognized this paradoxical situation and have attempted to find a partial solution through more extensive fellowship programs

and more effective industry-university relationships.

In large metropolitan centers late afternoon and evening programs have been initiated by local graduate schools in order to provide opportunity for part-time graduate study. More recently, where travel conditions appear to be unduly discouraging, off-campus graduate programs have been organized. Both represent a service to engineering education when they are carried on as high-level programs, but they give a false sense of achievement if they are not so conducted.

F. Part-Time Programs

Engineers who are confronted with difficult engineering problems soon appreciate the need for more extensive understanding of fundamental science and engineering science. Their undergraduate studies seldom permitted the extensive preparation in mathematics and physics required for real mastery of basic principles and their application to advanced engineering design or research.

Most frequently, part-time graduate programs are arranged to permit students to attend graduate classes after normal working hours. This arrangement places a heavy burden upon the graduate student. More important, however, is the requirement of a first-class faculty for these evening courses in order to merit the efforts of both institution and student. It is entirely inadmissible to entrust such graduate classes to untried teachers or to men without adequate educational experience. A strong background of practical experience is not sufficient justification for employing an individual as a graduate teacher either on a full-time or part-time basis. Since his appointment as a part-time teacher precludes close contact with other teachers in an academic atmosphere, previous teaching and research experience are essential.

If the course offerings are highly specialized so as to furnish graduate background in narrow field, outside experts might serve adequately or after some experience even in a distinguished manner as teachers. *However, if the course offerings tend to crystallize into a degree program, members of the full-time faculty must be available to teach at least the majority of the graduate courses.* It is particularly important for degree programs to operate with admission criteria identical with those practiced in the full-time graduate school and to maintain the same standards of performance. Injudicious mixing of auditors or poorly qualified students with candidates for graduate credit is strong evidence that the standards of the program are not at a master's degree level.

The full-time graduate student in a strong engineering school obviously has the advantage of informal association with outstanding faculty members. The evening student may have partial compensation through professional associations in his work. He is usually more mature, but in carrying two jobs he is commonly overworked. As a minimum standard he must have the opportunity, at least in the basic courses, to study under the leading faculty members in his field in order to receive adequate educational stimulation.

It is unnecessary to reiterate what has been emphasized elsewhere many times; the value of a degree is determined by the quality of the faculty that administers it. *A program of appropriate courses alone does not establish a strong graduate school;*

it must be supplemented by supervised advanced design or research conducted as a continuing program by a distinguished graduate faculty.

Critical understanding of the basic principles is most impressively demonstrated in a graduate thesis or in equivalent projects of major significance. Without such a creative contribution, whether it be creative design, original development, or research, the graduate degree has deteriorated to a certificate of limited scholastic attainment.

Although doctoral dissertations are now restricted generally to work performed in residence, nevertheless a considerable number of such theses have been completed *in absentia*. There is a widely held conviction within established graduate schools that the major doctoral degree should be awarded only for graduate work in residence that meets high academic standards.

G. Off-Campus Programs

All that has been said about possible shortcomings of indiscriminate part-time graduate course offerings is even more true of off-campus graduate programs. They are usually organized to meet the educational needs of a particular industry, group of industries, or a governmental research laboratory located an appreciable distance away from the nearest graduate engineering school. Often in their first conception they are not programs leading to degrees.

Unfortunately, more and more the demand has arisen to convert these off-campus programs into advanced-degree programs, in some cases allowing substitution of course work for the graduate thesis. *Real danger to the whole concept of graduate study can come from easy compromise both with respect to the quality of the faculty teaching such programs as well as to the facilities available and the quality of students admitted.* The feeling of obligation can be overpowering, yet the undertaking of responsibilities with inadequate faculty, library, and other facilities can lead only to grave criticism by the professional community and even by the students themselves. The near impossibility of maintaining the high standards expected of resident study without the extensive facilities on the campus has often been overlooked.

One necessary requirement must be the complete educational control of each program by the institution organizing it. Without prior experience in resident graduate study programs a faculty has more difficulty in appraising off-campus activities and should not undertake them.

The Committee feels that many off-campus graduate programs that have been in operation should not qualify for academic degree credit. The Committee also does not believe that any Master's or Ph.D. degree should be given on the basis of an appreciable amount of credit earned in off-campus work. It is possible that certificates or professional degrees may form appropriate acknowledgements of such achievement.

VII. CONCLUSION

The Committee has been concerned with what it believes to be reasonable, attainable objectives, rather than with Utopian goals on the one hand or minimum standards for accreditation

of undergraduate curricula on the other. Nevertheless, responses to the Preliminary and Interim Reports evidenced a wide desire to raise hitherto-accepted minimum standards, and it is anticipated that this Report will assist the Engineers' Council for Professional Development (ECPD) in attaining such a goal.

In closing this Report the Committee wishes to re-emphasize that it believes the spirit of its recommendation in advocating scientifically oriented undergraduate curricula must receive more attention than mere observation of proposed fractions of time devoted to particular areas. It gave a great deal of thought to the possibility of prescribing the level of attainment in each of the areas of importance in engineering education, but it was unable, except possibly in mathematics, to make a quantitative specification which would take into account the inherently dynamic nature of the basic sciences and more especially that of the engineering sciences. College faculties must perform this work year by year.

The task initially undertaken by this Committee is not finished nor can it ever be finished. The problem of the Evaluation of Engineering Education should always be in the consciousness of the members of faculties of engineering colleges. Each teacher must consider this task a vital personal one and approach it with intellectual vigor and full consideration for the needs of an expanding economy, requiring engineers with vision, creative ability, and sound training of truly fundamental nature. Since these desired qualities cannot be achieved for all students in an identical manner, elective study is recommended. The choice of electives at the undergraduate level contributes to the development of a stronger humanistic and social background for some engineers and a stronger scientific background for others with a resultant overall strengthening of the profession of engineering.

The interest and effort shown by the Institutional Committees make this Committee optimistic that improvement will be sought, and it therefore recommends the implementation of its Report at the local level. Improvement of engineering education is the responsibility of every teacher of engineering students.

APPENDIX A

Historical Background of Previous Evaluation Studies

Since the organization of the Society for the Promotion of Engineering Education in 1893 there have been many studies of engineering curricula which reviewed content of the several programs and gave a distribution of time to the major divisions of the work. Out of the study begun as the Mann Report, published as Carnegie Bulletin No. 11, came the Wickenden Report of 1923-29. It was followed by "Aims and Scope of Engineering Curricula" in 1940 and "Engineering Education After the War" in 1944, produced under the chairmanship of H. P. Hammond. D. C. Jackson's "Present Status and Trends of Engineering Education in the United States" was published in 1939, and its study of curricula may be considered as a supplement to the Wickenden Report.

Since the Wickenden Report is so basic and fundamental it may be desirable to quote a few sentences:

"The multiplication of trunk and branch curricula based on technical specialization has gone fully as far as can be justified. Further differentiation in courses for undergraduates is much more likely to proceed on functional lines."

"The most serious deficiency in engineering education is not so much in matter taught or matter omitted in college as in allowing the orderly process of education to stop, where it so often does, at graduation."

The 1940 and 1944 Reports, referred to above, emphasized the division of each curriculum into two major areas, titled the scientific-technological stem and the humanistic-social stem. These two studies renewed interest in the "general academic subjects" listed in The Wickenden Report. The wording used in describing the humanistic social stem is practically identical in both Reports and the time suggested for this area was twenty per cent of the total. This cultural program was to be an integrated sequence running through four years. During the last decade much thought and much study have been given to this phase of engineering education.

Both Hammond Reports recommended the four-year undergraduate program as the desirable norm. However, it was recognized that engineering graduates enter into many kinds of activity and that there should be comparable differentiation in their educational programs. In summarizing the 1944 Report, Dean H. P. Hammond outlined the needed preparation for widely varying engineering activities as follows:

"In order to provide for the satisfaction of the need incidental to these trends, the (1944) Committee suggests, for consideration, a plan of curricula differentiation in the fourth year, through which three options would be offered within each major professional curriculum: (1) Continuation of the present type of four-year program essentially as a terminal curriculum but with modifications advocated by the Committee, for a majority of students. (2) An alternative fourth year emphasizing subjects dealing with the management of construction and production enterprises. (3) A fourth year intended to prepare for additional years of advanced study by strengthening the student's command and extending his knowledge of basic sciences and mathematics, and by introducing him to the methods of advanced study. This fourth year, and the year or years of graduate study to follow,

would be planned as a unit rather than as two stages marked by the usual differences of undergraduate and postgraduate programs."

In 1950-52 the Society conducted a comprehensive study on methods of improving engineering instruction. This study resulted in publication of an ASEE Monograph entitled "Improvement of Engineering Teaching." This report dealt at considerable length with the problem of "how to prepare students to meet new situations with skill, resourcefulness, and leadership." It also treated the collateral problems of "how to instill in the student the desire to continue to learn after graduation and how to provide a cultural foundation which will encourage him to contribute to his local community and to civic groups as a mature, thinking human individual."

The principles of learning outlined in this report stressed "the importance of effective participation on the part of the learner; his motivation through the formulation of a goal; the clear definition of task assignments (preferably defined by the student himself); the evaluation of his progress; and his repeated practice in application." This project was participated in by committees in over 100 engineering colleges of the country.

In 1945 the Division of Graduate Studies of ASEE prepared a "Manual of Graduate Study in Engineering." This was completely rewritten in 1952, and reissued in monograph form. This Manual deals with the following: (1) the objectives of graduate study, (2) organization, (3) transitional studies, (4) developing a graduate faculty, (5) admission requirements, (6) degree requirements, (7) major, minor, and research, (8) the thesis, (9) language requirements, (10) mathematics, (11) examinations, (12) undergraduate courses, (13) non-technical studies, (14) evening classes, (15) cooperative programs, (16) sponsored research, (17) industry institutes, (18) foreign students, (19) student guidance, and (20) teaching loads.

The Committee on Evaluation of Engineering Education gladly acknowledges its debt to the many preceding committees that have reported on their studies of engineering education. Its work bears a close relationship to that of the committees that prepared the "Manual of Graduate Study in Engineering" and the report on "Improvement of Teaching in Engineering" because of the partial overlapping of the committee membership.

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Committee on Evaluation of Engineering Education, 1955

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