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FOR THE ADVANCEMENT OF TEACHING

A STUDY OF ENGINEERING EDUCATION

BY

CHARLES RIBORG MANN

BULLETIN NUMBER ELEVEN

1918

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PREPARED FOR THE JOINT COMMITTEE ON ENGINEERING EDUCATION OF THE NATIONAL ENGINEERING SOCIETIES

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PREFACE

THE present bulletin has been prepared under conditions somewhat different from other publications and bulletins of the Carnegie Foundation. This study of Engineering Education arose out of the action of a joint committee on engineering education, representing the principal engineering societies. More than three years ago the Committee had gathered a considerable amount of material bearing on the subject, and had come to the opinion that the work could be best carried out by the employment of some one trained in applied science, who should devote his entire attention to the study, working under the general direction of the Committee and in touch with it. The Carnegie Foundation agreed to appoint such a man and to bear the expense of the study. Professor Charles R. Mann, of the University of Chicago, undertook the work under these conditions, and the report which follows is the outcome of his studies under the general supervision of the Committee. The discussion of Professor Mann's report by the Committee forms the introductory chapter.

It will be understood that the report did not contemplate a study or examination of the engineering schools of the United States, altho a limited number of typical schools were visited and studied by Professor Mann. The point of view from which the study was undertaken was the following: Fifty years ago, when the engineering schools of the United States were inaugurated, they began their work upon a definite teaching plan and one that had at least pedagogic consistency. The course was four years. The first two were spent mainly in the fundamental sciences—chemistry, physics, mathematics, and mechanics; the last two years mainly in the applications of these sciences to theoretical and practical problems.

In the half century that has passed this course of study has been overlaid with a great number of special studies intended to enable the student to deal with the constantly growing applications of science to the industries. While the original teaching plan remains as the basis of the four-year engineering curriculum, the courses given in most schools have been greatly modified in the effort to teach special subjects. As a result, the load upon the student has become continually heavier and bears unequally in different places and in different parts of the course. In addition there is a widespread feeling that under this pressure the great body of students fail to gain, on the one hand, a satisfactory grounding in the fundamental sciences; and on the other hand, do not fulfil the expectations of engineers and manufacturers in dealing with the practical problems with which they are confronted on leaving the engineering schools.

It is out of this situation that the Committee of the Engineering Societies began its study, whose purpose is not so much to record the details of engineering teaching in the various schools as to examine the fundamental question of the right methods of teaching and of the preparation of young men for the engineering professions: in other words, to question anew the pedagogic solution of fifty years ago, to examine the curriculum of to-day and the methods of teaching now employed, and to suggest in the light of fifty years of experience the pedagogic basis of the course of study intended to prepare young men for the work demanded of the engineer of to-day. In the effort to do this, the point of view of the teacher, of the engineer, and of the manufacturer and employer has been kept in view.

While the report and the introduction of the Committee deal with many matters of detail in the formation and development of a suitable curriculum, and suggest various methods for simplifying the present courses of study, three questions of importance are raised which are closely related to the primary purpose for which the engineering school exists.

Professor Mann argues that the present arrangement, under which the fundamental sciences are taught in advance of their applications, is the wrong method of teaching, and that the engineering education will never be satisfactory until theory and practice are taught simultaneously.

For example, mathematics is the most important tool of the engineer. It is taught for two years in the engineering school in separate courses—higher algebra, coördinate geometry, the calculus, and mechanics. The splitting up of mathematics into separate courses is itself a source of weakness from the standpoint of the student's needs. He needs not studies nor recitations in these artificial divisions of mathematics, but a single course in mathematics illuminated and made alive at every step by applications in the solutions of actual problems. Algebra, coördinate geometry, and the calculus are not separate and unrelated studies, but merely parts of the one subject of mathematics.

As a consequence of this method of teaching Professor Mann urges that the engineering courses, as taught in the preliminary years, do not form sound criteria for judging as to the ability of the student to do successful engineering work, and that many students are sent away from the technical school without having had any fair test as to their capacity for engineering practice or study.

In the third place he gives the results of certain objective tests designed to throw light upon the fitness of the applicant to undertake engineering studies and practice. It is quite clear that the trial of these tests made hitherto is not sufficient to demonstrate their trustworthiness, but the question raised is an exceedingly interesting one. There are few devices connected with teaching more unsatisfactory than our present day examinations, whether used as tests for admission or as criteria of performance on the part of the student.

In general these suggestions of Professor Mann, if carried out, would affect present day teaching of engineering in much the same way that Langdell's case method revolutionized the teaching of law.

Langdell built the teaching of law exclusively and directly upon the study of cases. His notion was that the principles upon which the law rests are few in number, and that these could be best apprehended and mastered by the student in the direct examination of typical cases. The number of such cases necessary to illustrate these principles he held to be very small in comparison with the overwhelming mass of law reports to which the student had formerly been directed as the basis of the study of the law in conjunction with textbooks. Langdell's method involved the working out by the student of the principles of the law from actual cases tried and decided in the courts. Law he conceived of as an Applied Science.

Langdell's method is not infrequently referred to as the laboratory method of teaching law, conveying the impression that the case method of teaching law consists in transferring to the teaching of law the methods employed in the teaching of applied science. This statement has been the cause of no little confusion. The teaching of law by the case method presents only a remote analogy with the methods hitherto employed in teaching applied science. Applied science is not taught ordinarily in the engineering school by the case method. On the contrary, the methods actually employed in teaching the so-called laboratory subjects do not differ appreciably from the methods of teaching literature or Latin. At present the student undertakes to learn a vast body of theory under the name of physics, mechanics, or chemistry, illustrated in some measure in the laboratory, and then seeks later to select from this mass of knowledge the principles to be applied, for example in electrical engineering. The case method would proceed in directly the opposite manner. Taking up, for example, the dynamo as a "case,"—that is, as an illustration of physical laws in their actual concrete working,—it would proceed to analyze the machine for the purpose of discovering the fundamental physical or mechanical principles involved in its operation. It would lead the student from practical applications by analysis to a comprehension of theory, instead of from theory to applications as under present methods of teaching.

It is an interesting fact that while much is said about the teaching of science in the modern school, the methods of teaching science are actually but little changed from those employed in teaching the subjects that filled the curriculum before the teaching of science began in the school. The practical suggestion of this report is that the case method of teaching is truly scientific and that the present methods of teaching applied science are unscientific. Furthermore, as an essential feature of the new method of teaching science, Professor Mann would combine theory with practice much more intimately than occurs in the law schools of the present day, by requiring the student to learn to operate the "case" under study. The student must not merely observe and analyze the operation of the dynamo: he must also actually run it and repair it when out of order. The method of teaching he advocates for engineering students, while based on the same conceptions as Langdell's pedagogic innovation, is designed to meet some of the objections commonly raised to-day against even case method law schools.

Whatever may be thought of this contention, the subject is one of great significance, and worthy of the attention of teachers and engineers. Engineering schools, like all institutions of learning, are slow to undertake educational experiments. It is sometimes easier to start a new school than to try an educational experiment in an old one. But obviously an actual experiment thoroughly carried out would be the only satisfactory demonstration of the soundness of the case method of teaching science.

The report is published by the Carnegie Foundation as a work of coöperation with the great engineering societies, and with the hope that the formulation of these important enquiries and their discussion may lead to a serious effort on the part of those having to do with engineering education to reëxamine the curricula of the schools, and to approach the problem of their improvement not only from the standpoint of the teacher, but also from that of the practising engineer and of the employer.

HENRY S. PRITCHETT,
President of the Carnegie Foundation.

INTRODUCTION

The Society for the Promotion of Engineering Education, at its Cleveland meeting in 1907, invited the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, and the American Chemical Society, to join the Society for the Promotion of Engineering Education in appointing delegates to a "'Joint Committee on Engineering Education' to examine into all branches of engineering education, including engineering research, graduate professional courses, undergraduate engineering instruction, and the proper relations of engineering schools to secondary industrial schools, or foremen's schools, and to formulate a report or reports upon the appropriate scope of engineering education and the degree of coöperation and unity that may be advantageously arranged between the various engineering schools."

At the Detroit meeting in 1908, a resolution was passed authorizing this Committee to invite the Carnegie Foundation for the Advancement of Teaching and the General Education Board to appoint delegates.

Notwithstanding the appropriation by the American Society of Civil Engineers of a sum to assist in the investigation, it was found to be utterly impracticable to carry on the work without larger funds, and the Carnegie Foundation was thereupon urged to undertake the work on a comprehensive scale. After proper examination, the Foundation generously acceded to this request, and finally selected Professor Charles R. Mann to make a careful investigation and report.

In presenting Professor Mann's report, the Committee desire to state that they have been closely associated with Professor Mann during his investigations, and have frequently conferred with him in the progress of the work and in the different plans adopted for securing information. Many of the conclusions reached have been discussed at public meetings of educational experts and have had the advantage of mature judgment and long experience. The views of the whole engineering profession, widely scattered throughout the country and representing every phase of professional activity and practice, were ascertained. The results of some of these special enquiries were published and considered by the engineering societies; they were both interesting and surprising, and are set forth in Chapter XVI of the report.

Notwithstanding this varied experience, it was not until the Committee had the advantage of examining advance copies of Professor Mann's report that they realized the coördination existing between all of the different portions of the investigation, and their bearing upon the value of the whole study.

We believe that this report possesses particular significance on account of the simple and clear treatment of the complicated problems involved. The history of the origin and development of the schools is concisely told, and the connection between the curriculum and the changing demands of industrial activities and growth is clearly narrated. If the study went no farther — and this is but the threshold of the report — we believe the value of this result alone would go far toward repaying the expense of the enquiry, liberal as that has been.

Other significant characteristics of the report are found in the discussions of the general failure to recognize such factors as "values and cost," the importance of teaching technical subjects so as to develop character, the necessity for laboratory and industrial training throughout the Courses, and the use of good English.

Valuable suggestions are offered for avoiding or reducing present difficulties found in many other directions, and all of the problems have been treated in a broad and comprehensive spirit. No hard and fast rules are laid down for the government of engineering education. Such a course would inevitably increase the difficulties of future advances. Changes must be made from time to time to meet conditions as they arise, and any attempts to solve the problems of engineering education must be of so flexible a nature as to admit of improvements.

We now turn to a few of the principal points emphasized in the report. Professor Mann has called attention to the waste occurring in educational efforts arising from lack of coördination shown in the histories and aims of the technical schools as set forth in the first chapter of this study.

Another point is the perplexing one of the regulation of admissions. At present sixty per cent of those who enter the schools fail to graduate. The importance of limiting admissions more strictly to those students who possess some aptitude for engineering is demonstrated, and a substitution of objective tests in place of those of a subjective character is recommended.

Another point emphasized, and one of deep importance, is that of the reorganization of curricula which are commonly acknowledged to be much congested, and which it is stated will continue, "as long as departments are allowed to act as sole arbiters of the content of the courses." Plans are offered for developing particular types of curricula suited to the environment of each school.

Emphasis is also given to the necessity for a broader training in the fundamentals of science as an equipment for all engineers and forming a sort of "common core" to every curriculum. With this broad training in the first and second years the student is expected to develop some natural leaning toward a specialty, and then will follow vocational guidance in the later stages of his education.

Among the questions that will perhaps occur to many interested in the status and progress of engineering education, in connection with this report, are—How far will the recommendations in the report be applicable to present conditions? and what will be the possible influence of this study upon education and practice? These questions are of course difficult to answer with precision. We can only form an estimate, based upon experience and knowledge of the present chaotic condition of the schools, arising from world-wide events over which they are called to exercise a powerful influence. There probably never was a time when the minds of teachers were so intently alive and receptive to rapid changes, as at the present moment. This report, made under the auspices of the Carnegie Foundation and with the direct assistance of this Committee, will be read and studied all over the country, as soon as it becomes available. Engineering educators are already partially familiar with the trend of the report. They, better than others, know from long experience something of the difficulties in establishing standards by which to measure the successes or failures of their efforts to provide proper training for engineers. It may take time to convince all that a measure, or scale, has been created by the practising engineers of the country by which an estimate may be formed of the amount of success in engineering teaching, irrespective of the special courses involved. That scale is the improvement of character, resourcefulness, judgment, efficiency, understanding of men, and last of all, technique, as shown by students. These facts have already been published and widely circulated, and since they became known there are probably few intelligent educators who have not asked themselves the question—Am I so teaching as to produce these results in my pupils and in the order of value specified by the engineering profession? It may perhaps be considered not unreasonable for this Committee to believe that if portions of this study have already proved of value and interest to the schools, there is some secure foundation for thinking that the whole report will awaken wide interest because of the applicability of its results, and that its influence on engineering education will be beneficial.

In addition to its possible effects on professional educators, we entertain the hope that it will also have a wider significance as an important contribution to the general cause of education. The publication of the study in the present emergency, when the Government is so deeply concerned with so many vital questions connected with educational processes, may assist also in the solution of some of the many problems arising in connection with vocational training in the different branches of military science.

American Society of Civil Engineers
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American Society of Mechanical Engineers
F. H. Clark, Fred J. Miller

American Institute of Electrical Engineers
C. F. Scott, Samuel Sheldon, *Secretary*

American Chemical Society
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American Institute of Chemical Engineers
J. R. Withrow

American Institute of Mining Engineers
Henry M. Howe, John Hays Hammond

Society for the Promotion of Engineering Education
D. C. Jackson, G. C. Anthony, C. R. Richards

Joint Committee on Engineering Education of the National Engineering Societies.

PART I

PRESENT CONDITIONS

Chapter I

THE DEVELOPMENT OF ENGINEERING SCHOOLS IN THE UNITED STATES

During the Colonial period industrial production in America was almost wholly confined to agriculture. All forms of manufacture were systematically discouraged by acts of Parliament. Iron mining was encouraged, provided the product was shipped to England as pig iron; but all tools, implements, guns, gunpowder, and machinery used in the colonies had to be purchased in the mother country. This effort to limit American production to agriculture and raw materials was one of the chief causes of the War of Independence.

When the supply of goods from British factories had been cut off by the non-importation agreement between the colonies (1774), clothing, gunpowder, tools, and equipment soon became scarce. An immediate need arose for skilled workers in all the mechanic arts. Congress sought to meet this need by urging the establishment in every colony of a Society for the Improvement of Agriculture, Arts, Manufactures, and Commerce, and by offering premiums for the best achievement in every essential line of industry. Enough was accomplished by these means to carry the war, with the help of France, to a successful termination.

After the war England sought to crush the incipient American industries by selling her goods here at lower prices than were charged at home. The Confederation was threatened by an industrial domination that seemed no less oppressive than political domination. This crisis was met, first, by the formation of numerous societies for the promotion of the useful arts, to encourage a spirit of enquiry, industry, and experiment among the members; second, by offering premiums from state treasuries for such improvements in the useful arts as might seem beneficial to the country; and third, by inviting trained artisans from abroad to settle here and give America the benefit of their training. It was on this basis that Samuel Slater, a skilled English worker from the Arkwright factory, established at Pawtucket in 1790 the first successful textile mill driven by water power.

The real beginnings of American engineering were made at this time under the spur of a patriotic spirit of industrial independence. In 1793 Eli Whitney invented the cotton gin, which determined the industrial future of the South. Oliver Evans made the first machinery for flour mills in 1787, and in 1801 constructed the first high-pressure steam engine. Philadelphia equipped its water works with a double steam pump that had a capacity of 3,000,000 gallons a day, built by Nicholas I. Roosevelt in 1801. Six years later Robert Fulton made his famous trip up the Hudson in the Clermont. The Santee canal in South Carolina was begun in 1786. Work was started on the Middlesex canal in Massachusetts and on the canal joining the Schuylkill and the Susquehanna rivers in Pennsylvania in 1793. The mechanical inventions were made by Americans who had no formal engineering training; the canals were built by foreign-trained civil engineers.

The effect of the War of 1812 was similar to that of the War of Independence. For three years American production was stimulated by being thrown on its own resources. This was followed by a period of stimulation due to foreign competition. By 1812 the exhaustion of the soil because of unscientific methods of agriculture was already driving the population to seek new land in the West. There arose a loud cry both for instruction in better methods of farming in order that the farms might not be deserted, and for better means of transportation to the West. To meet the latter, the Erie Canal (1817–25) was built. This was the first great achievement of American engineering, because the work was done by three self-trained Americans, James Geddes, Benjamin Wright, and Charles Brodhead.

The demand for scientific information to increase production in agriculture and domestic manufactures is voiced in an enormous number of memorials, petitions, and committee reports to the various state legislatures. Of these the Report of the Committee on Agriculture presented by Jesse Buel to the New York State legislature on March 29, 1823, is perhaps the most complete and expressive. This report urges the establishment of a tax-supported school of agriculture along the lines that had proved so successful at the Fellenberg School at Hofwyl, Switzerland. Full details of the plan, the methods, and the results to be expected are given. It was stated, finally, that if the state would undertake the support of the school, the Hon. Stephen van Rensselaer would donate the necessary land. The proposal was rejected by the legislature.

The following year Mr. van Rensselaer established at Troy the pioneer school of its kind in the United States, the Rensselaer Polytechnic Institute. At the beginning a new type of instruction was used, but it proved too expensive. In 1829 the curriculum was revised, a course in civil engineering added, and for a quarter of a century this school divided with the West Point Military Academy the honor of supplying men with scientific training to meet the country's need for engineers. Many of the early graduates of both schools won renown in designing and building the pioneer highways, bridges, canals, and railroads that led to the conquest of the West.

For engineering education the striking features of this period from 1770 to 1830 are the gradual and persistent growth of the demand for scientific information for the purpose of increasing production, and the scanty attention given to devising ways and means of satisfying it. After twenty-three years of keen discussion, the Rensselaer Polytechnic Institute, which soon specialized in civil engineering, and the West Point Military Academy, which was intended for a totally different purpose, were the only two scientific schools in the country.

In the fifty years from 1820 to 1870 the industrial conditions in the United States were completely reorganized. During this period the percentage of the working population in agriculture dropped from 83 to 47.6; while in manufacturing, trade, and transportation it increased from 17 to 31.4. In addition a new class called personal service, claiming 18 per cent of the workers, was added and the professional group expanded from a negligible per cent in 1820 to 3 per cent in 1870. Thus the advent of the steam engine, the railroad, and the reaper reduced the number of farmers by 354 out of every 1000 workers, increased the number in manufacturing, trade, and transportation by 144, and created the new trade of personal service, giving occupation to 180 per thousand. The professional group also expanded to include 30 per thousand. The number of patents increased in this same period from about two hundred to over thirteen thousand per year.

A high degree of engineering ability was required to accomplish this industrial revolution. Among the civil engineers who took part were a number who had the advantage of scientific training either at Rensselaer or at West Point. But in the long list of mechanical engineers who built the locomotives, the steam engines, the machine tools, and the farm machinery, it is difficult to find a single one who had any special school training for the work. As science developed and machinery became more and more complex, the need of special training for the mechanical engineer became more pressing. Hence the period from 1820 to 1870 may be said to have indicated the value of special training for the civil engineer, and to have defined the need for trained mechanical engineers for industrial production.

Scattered here and there in the vast mass of pamphlets, petitions, memorials, and reports, addressed to various legislative bodies during these years, urging the establishment of state schools for training in mechanic arts, there appears another conception that added inspiration to the industrial demand for schools of science. It is to the effect that thorough training in science must not only increase production, it must also raise agriculture and mechanic arts to the rank of the learned professions like theology, medicine, and law. In the Buel report just mentioned it is urged that because agriculture is the basis of all industry, it should be elevated to the rank of a liberal and fashionable study. The well-known phrase in the Morrill Act—"to promote the liberal and practical education of the industrial classes in their several pursuits and professions in life"—implies the same conception. Some of the earliest engineering schools were called Industrial Universities.

It thus appears that the clearly defined practical demand for training in science as an aid to industrial production was blended with a vaguely defined ideal of liberal training thru science. These were the forces that gave scope to engineering in America and compelled the development of the schools.

At first this development was very slow. In spite of the widespread recognition of the need, the Rensselaer Polytechnic Institute remained for twenty-three years the only school of its kind. At length in 1847, thru private benefactions, the Lawrence Scientific School was established at Harvard and the Sheffield Scientific School at Yale. The University of Michigan also voted that same year to offer a course in civil engineering. These were the only additional engineering schools opened before the

Civil War, and they had a hard struggle for existence because their aims seemed dangerous to academic traditions.

During the Civil War Congress passed the Morrill Act (1862) granting federal aid to the several states for founding colleges of agriculture and mechanic arts. State legislatures that had for years been deaf to all appeals now quickly accepted the federal grants and voted to create the new type of school. Established colleges caught the spirit and added departments of engineering. The four schools of 1860 increased to seventeen by 1870, to forty-one by 1871, to seventy by 1872, and to eighty-five by 1880. Now there are one hundred and twenty-six engineering schools of college grade, of which forty-six are land grant colleges operating under the Morrill Act, forty-four are professional schools in universities, twenty are attached to colleges, and sixteen are independent. The number of students has increased from fourteen hundred in 1870 to thirty-three thousand in 1917, and the annual number of graduates in engineering from one hundred in 1870 to forty-three hundred. Then there were less than three graduates per million population, now there are about forty-three per million.

The rate of growth of the schools has not been constant. In the decade 1870–80 the number of graduates per million population increased from three to four. The figures for the successive decades are:

Decade ending	*Graduates per million*	*Increase per million per year*
1860	1	
1870	3	0.3
1880	4	0.1
1890	10	0.6
1900	17	0.7
1910	36	1.9
1916	43	1.1 (6 years)

It is to be noted that growth was rapidly accelerated from 1870 to 1910, especially during the last decade. Since 1910 the growth has been less phenomenal.

This increase in the number of graduates indicates another important change in school conditions. In 1870 the ratio of graduates to the total number of students was one hundred to fourteen hundred, or one to fourteen. In 1915 this ratio was forty-three hundred to thirty-three thousand, or one to seven and seven-tenths. This indicates that a much larger proportion of the students now take the full course; that is, there are relatively fewer stragglers. Back in the '70's the mortality was in many cases as high as 90 per cent, that is, only ten out of every hundred freshmen continued thru the whole course. Now the highest mortality among the schools visited[1] is 75 per cent, and the average for the twenty schools is 60 per cent. Hence the schools have not only increased in size, but their work has been better systematized and standardized.

From figures published by Mr. A. M. Wellington in the *Engineering News* for 1893

[1] See page 82.

and from data presented in the Reports of the United States Commissioner of Education it appears that the total number of engineers graduated in the succeeding decades was approximately

Prior to 1870	866
1871–1880	2,259
1881–1890	3,837
1891–1900	10,430
1901–1910	21,000
1911–1915	17,000

The total number of engineering degrees granted in the United States up to 1915 has therefore been about 55,000. In 1911 the eleven technical high schools of Germany were graduating engineers at the rate of 1800 per year, and the total number of graduates up to that date was 14,215.

In addition to the hundred and twenty-six engineering colleges just discussed there are forty-three degree-giving institutions that pay some attention to engineering work. Of these, eighteen are arts colleges that claim to give "two years of engineering;" sixteen advertise engineering courses, but have neither the faculty nor the equipment to give them well; four are military schools which occasionally graduate a civil engineer; and five are privately owned institutions which endeavor to teach engineering to all who apply, without regard to previous academic training, and grant a considerable number of degrees on this basis. There are also many excellent schools, like the Wentworth Institute, the Lowell Institute, and the Franklin Union in Boston; the Baltimore Polytechnic Institute, Pratt Institute, the Bliss Electrical School in Washington, the Casino Night School in Pittsburgh, the Dunwoodie Institute in Minneapolis, the Cogswell Polytechnic in San Francisco, and the numerous technical classes of the Young Men's Christian Association in various places, that teach engineering but make no pretense of granting college degrees. These schools are meeting a real need in a genuinely effective way without departing from their vocational purpose or confusing the educational situation by granting degrees.

The first schools offered only one course — civil engineering. The Massachusetts Institute of Technology opened in 1865 with six curricula leading to degrees in civil, mechanical, and mining engineering, practical chemistry, architecture, and general science. Now the specialized courses at the Institute have increased to fifteen and numerous other specialties are offered at other schools. The additions include all phases of engineering, such as chemical, sanitary, metallurgical, marine, cement, electrochemical, textile, automobile, aeronautical, ceramic, highway, agricultural, and engineering administration. The work of the schools has thus increased in scope and become more complex.

Unfortunately it is not possible to give any even reasonably trustworthy figures as to the resources and the equipment of all the engineering schools, because so many of them are inextricably bound up with colleges and universities. The United States

Bureau of Education still treats engineering under the general heading "Universities, Colleges, and Technological Schools." In a university with several schools it is a very perplexing problem to determine how much of the total equipment and expense should be charged against any one division such as engineering. In order to secure some estimate of the cost and resources of engineering education, as distinguished from college education, the following summary of the conditions at the sixteen independent schools that devote all their resources to engineering alone is presented. The figures are from the Report of the United States Commissioner of Education for 1916.

In the sixteen independent schools there were, during the year 1914–15, 762 instructors and 6807 students; or on the average one instructor to nine students. The total expenditure for the year was $2,348,000, or an average of $345 per student. The plants were valued at $14,047,000, the equipment at $3,022,000, and they had endowments amounting to $12,985,000.

These sixteen schools are widely distributed over the country, the number of instructors varies from 5 to 290, the number of students from 26 to 1816, the value of the plant from $98,000 to $6,300,000, the endowment from nothing (at state schools) to $3,236,000, the value of equipment from $51,000 to $478,000, and the cost per student year from $204 to $1333. Seven are state institutions and nine are on private foundations. It is therefore not unreasonable to assume that the conditions that maintain for the 6807 students of these schools are typical of conditions for the 33,000 students in all schools. On this assumption, the total annual expenditure for the engineering instruction of 33,000 students at $345 per year is $11,385,000. On the same assumption the total value of the plants used for this purpose is about $68,000,000, the equipment is worth about $15,000,000, and the endowment is about $63,000,000. Altho these figures are merely estimated, they are as trustworthy as any that are available under present conditions.

Since the engineering schools entered upon their remarkable development fifty years ago the conditions of industrial production have changed, new fields of engineering have been developed, the professional ideals of the engineer have grown more definite, laboratory work has won recognition as an essential element of all instruction in science, and educational theory and practice have been brought within the range of scientific test. Under these conditions numerous fundamental questions concerning engineering education have of necessity emerged. Do we need fewer or more schools? Is the curriculum too long or too short? Should the engineering school be made a graduate professional school? What are the present demands of science, of industry, and of education? How well are the schools meeting these demands? What changes, if any, seem desirable?

The answers to questions like these are at present both vague and unconvincing. This study endeavors to define a number of the more important problems of engineering education, and to suggest policies and methods that promise to be fruitful in working toward more satisfactory solutions.

Chapter II

THE AIMS AND CURRICULA OF THE EARLY SCHOOLS

Engineering schools are so obviously a result of the needs of industrial production that the conceptions on which they are founded are necessarily much the same for all. Hence three schools—the Rensselaer Polytechnic Institute (1824), the University of Illinois (1867), and the Massachusetts Institute of Technology (1865)—are here selected as typical expressions of the general movement, because the documents relative to the founding of these institutions state their ultimate aims with striking clearness.[1]

From the evidence presented in the *History of the Rensselaer Polytechnic Institute* it appears that in planning his school Mr. van Rensselaer was strongly influenced by two foreign institutions: namely, the Royal Institution of Great Britain, which was established by Count Rumford in 1799 as an offshoot of the Society for Increasing the Comforts of the Poor, and was intended to facilitate the general introduction of useful mechanical inventions; and the Fellenberg School at Hofwyl, Switzerland, which sought to educate the children of the poor thru manual work in accordance with methods devised by Pestalozzi. As stated in the official notice of the establishment of the school, its aim was to furnish instruction "in the application of science to the common purposes of life," in order to train men to teach "the sons and daughters of farmers and mechanics . . . and who will be highly useful to the community in the diffusion of a very useful kind of knowledge, with its application to the business of living."[2] Prior to 1829 no mention of professional engineers is made beyond the remark in the Buel report (page 5), that because agriculture is the basis of all industry, the state should elevate it "to the rank of a liberal and fashionable study."

The educational conceptions of the land grant colleges developed gradually during the quarter century from 1825 to 1850. They are expressed in numerous memorials to the Federal Congress, petitions to state legislatures, and resolutions of societies for the promotion of agriculture and the mechanic arts. An analysis of the more important of these documents and of the debates in Congress on the several Morrill acts has just been published by the Carnegie Foundation for the Advancement of Teaching in Dr. I. L. Kandel's Bulletin on *Federal Aid for Vocational Education*. These conceptions reached their fullest expression in the meetings of the Illinois Industrial League in 1851–53. A very complete statement of the aims of the new schools is made in a memorial sent by the league to the state legislature in 1852.[3]

[1] Cf. P. C. Ricketts: *History of the Rensselaer Polytechnic Institute*, New York, Wiley, 1895; W. B. Rogers: *Objects and Plan of an Institute of Technology*, Boston, 1861; E. J. James: *The Origin of the Land Grant Act of 1862*, *University of Illinois Bulletin*, vol. viii, No. 10, November, 1910.

[2] Ricketts, *loc. cit.*, pages 6-10.

[3] E. J. James, *loc. cit.*, pages 90-95.

In this document the memorialists state that as members of the industrial classes personally engaged in agricultural and mechanical pursuits they have forced on their attention constantly the fact that from one-third to one-half of the products of the state are annually sacrificed because of the worker's ignorance of scientific laws and methods of work. This appalling loss might be prevented if there were established a suitable industrial university to teach what is already known and to carry on investigations of new problems. To secure these ends, it is necessary to establish industrial universities which shall give the industrial classes a thorough scientific and practical training equivalent in all respects to the literary training already given so successfully and abundantly as preparation for the so-called learned professions.

The educational aims and methods required for this purpose were stated forcefully by Professor J. B. Turner in two addresses which are reprinted in President James's pamphlet. In these Professor Turner makes clear that the conventional forms of instruction in literary colleges are not suitable for industrial training. Book learning alone does not suffice, but must be supplemented by a study of things. The former produces "laborious thinkers," while industry needs "thinking laborers." Nor are schools that teach the application of science to the art of killing men fitted to teach scientific methods of feeding, clothing, and housing men. A special type of instruction is needed,—one that analyzes practical problems and sets the student "to earnest and constant thought about the things he daily does, sees, and handles, and all their connected relations and interests." Men secure true discipline best by "continued habits of reading, thought, and reflection in connection with their several professional pursuits in after life." In this way schools can "teach men to derive their mental and moral strength from their own pursuits." There are "more recondite and profound principles of pure mathematics immediately connected with the sailing of a ship, or the moulding and driving of a plow, or an axe, or a jack-plane than with all three of the so-called learned professions together," and these should be made objects of study in order to "extend the boundaries of our present knowledge in all possible practical directions."

It is to be noted that the aim of the founders of the "Illinois Industrial University" was increased production and professional recognition. The conception of the need and the methods of training farmers and artisans for increased production in such a way as to elevate their callings to the rank of professions is, however, much more definitely expressed than in the case of Rensselaer. The need for expanding the bounds of knowledge by scientific investigation has also been perceived.

At the Massachusetts Institute of Technology the aims and methods were defined by its first president, William B. Rogers. The seeds of the conception of a polytechnic school were planted in him during his first experience in teaching apprentices at the Mechanics Institute in Baltimore in 1827. The growth of the plan was fostered by his share in the preparation, in 1837, of a petition for the Franklin Institute to the Pennsylvania State Legislature praying for the establishment of a state school of applied science, and by his formulation for his brother in 1846 of a "Plan for a Polytechnic School in Boston."[1]

The final statement of his conceptions was printed in his *Objects and Plan of an Institute of Technology*, Boston, 1861. In this pamphlet, which was issued to attract support for the enterprise, the argument is this: "Material prosperity and intellectual advancement are felt to be inseparably associated" (page 1). But material prosperity requires intelligence in industrial production, and this in turn demands "that *systematic training in the applied sciences*, which can alone give to the industrial classes a sure mastery over the materials and processes with which they are concerned. Such a training, forming what might be called the intellectual element in production, has, we believe, become indispensable to fit us for successful competition with other nations in the race of industrial activity, in which we are so deeply interested" (page 20). Such a training should not only impart knowledge and develop habits of exact thought; it should also "help to extend more widely the elevating influences of a generous scientific culture." There should also be included "a department of investigation and publication, intended to promote research in connection with industrial science" (page 6).

It appears from the foregoing pages that from the beginning the engineering schools have had a clear conception of their functions. They themselves understood that their ultimate aim was increased industrial production, and that their special contribution to this end was systematic instruction in applied science. In addition they believed that if this instruction were given with the proper spirit, engineering would become a learned profession and scientific research a recognized necessity.

The means employed at Rensselaer in 1824 to secure these ends were novel and unique. The first curriculum required one year for its completion, and was divided into three terms. School opened the last week in July with an "experimental term," during which the students gathered botanical, mineralogical, and zoölogical specimens, visited shops and factories near the school, and discussed with the class the significance of what they had collected and observed. In addition each student gave a number of lectures on chemistry and natural philosophy, fully illustrated by experiments performed with his own hands.

During the second term, from the end of November to the first of March, the students reviewed in class the sciences taught in the fall, and in addition studied rhetoric, logic, geography, and mathematics. The spring term lasted from the first week in March to the end of June. For six weeks the work consisted of lectures by the students on experimental philosophy, chemical powers, substances non-metallic, metalloids, metals, soils, and mineral waters. For the remaining nine weeks the students were exercised in the application of the sciences to practical projects and in the study of engineering works in the neighborhood of the school.

[1] William Burton Rogers: *Life and Letters*, vol. i, pages 420–427.

In the catalogue published in 1828 the term "civil engineering" occurs for the first time, as one of the topics on which the senior professor would lecture. The catalogue for 1831–32 states that the second sub-term would be devoted to "Trigonometry, Navigation, and the Elements of Civil Engineering." In 1835 the legislature was petitioned to amend the charter of the school so as to permit the addition of a "department of mathematical arts, for the purpose of giving instruction in engineering and technology." Graduates of this department were to receive the degree of Civil Engineer. This degree was awarded for the first time in the United States to four members of the class of 1835.

It will be noted that during the first ten years the Rensselaer Institute evolved from a school of natural science designed to train teachers able to spread among farmers and artisans scientific information that would assist them in production, into a school of engineering and technology. The changes in curriculum that accompanied this evolution are striking. The full program for 1835 is printed in President Rickett's History. A comparison of this curriculum with the first one shows that the "experimental term" at the beginning has disappeared. The school year begins in November with class work in "practical Mathematics, Arithmetical and Geometrical," combined with "extemporaneous speaking on the subjects of Logic, Rhetoric, Geology, Geography, and History," and "Lectures on National and Municipal Law" by the senior professor. The second term of twenty-four weeks devotes eight weeks to practice in the use of instruments; eight weeks to study of the theory of mechanical powers, bridges, arches, canals, etc.; four weeks to calculations of the quantity of water per second supplied by streams with reference to their use for various practical purposes; and four weeks to inspection of "mills, factories, and other machinery or works which come within the province of mathematical arts."

This evolution of the curriculum was carried one step farther in 1849, when the director, Professor B. Franklin Greene, went abroad and made a careful study of French technical schools. On his return the course at Rensselaer was lengthened to three years and a new curriculum adopted. This curriculum is a combination of the curricula of L'Ecole Centrale des Arts et Manufactures, which plans to train civil engineers, directors of works, superintendents of factories, and the like; and L'Ecole Polytechnique, which prepares for certain government technical institutions. The first half of the curriculum was intended to lay the general scientific basis of all engineering, and the second half to develop proficiency in some special line. This curriculum is given here in full along with the first three years of the first curricula of the Massachusetts Institute of Technology (1865) and the University of Illinois (1867).

Rensselaer	Massachusetts Institute	University of Illinois
	First Year	
Algebra, geometry, trigonometry	Algebra, solid geometry, trigonometry	Algebra, geometry, trigonometry
General physics	Elementary mechanics	
Geometrical drawing	Drawing — mechanical and freehand	Descriptive geometry and drawing
English	English	English or
Foreign language	Foreign language	Foreign language
Surveying	Chemistry — inorganic	History
Botany		Botany
	Second Year	
Analytics, calculus	Analytics, calculus	Analytics, calculus
General physics	Physics	
Chemistry	Chemistry	
Descriptive geometry, machine drawing	Descriptive geometry, machine and freehand drawing	Descriptive geometry, drawing
Topographical and hydrographical surveying	Surveying — plane	Surveying
English	English	
Foreign language	Foreign language	Foreign language
Mineralogy	Astronomy, navigation	
Zoölogy		
Geology		
	Third Year	
Mechanics	Calculus, analytic and applied mechanics	Calculus, analytic mechanics
Practical astronomy	Spherical astronomy	Descriptive astronomy
Geodesy — trigonometrical, railroad and mine surveying	Surveying — roads, railroads and canals	Railroad surveying
Descriptive geometry — perspective, topographical drawing, stereotomy	Descriptive geometry — masonry and carpentry	Shades, shadows, perspective
Industrial physics		
English	Physics	Physics
Practical geology	English	
Physical geography	Drawings, plans, etc.	
Machines	Foreign languages	Chemistry
Constructions — theory of structures, bridges, hydraulic works, railways	Computation of earth work and masonry	
Mining		
Metallurgy		
Philosophy of mind	Hydrographical surveying	

The curricula at the Massachusetts Institute and the University of Illinois did not evolve thru a period of years. They were simply adopted in the form given. How much influence the Rensselaer curriculum had in shaping the others it is impossible to say. Internal evidence suggests that this influence was large.

A comparison of these three curricula indicates that the general plan is very much the same in all. The third year at Rensselaer contains some of the technical courses that appear in the fourth year of the other two schools. But they all agree in placing mathematics, drawing, descriptive geometry, physics, and chemistry before the work in applied science. In other words, they all sought to meet the demand for increased production by first teaching the necessary theoretical science and then showing how to apply it. This was the plan in the French schools, and it was transplanted without change to America. It remained and still is the prevailing conception underlying the curricula of our engineering colleges.

But tho these three curricula agree in general plan, the methods of handling the work in the three schools were quite different. The system of instruction by the students, which has already been described, had by 1865 given place at Rensselaer to the system now used there of interrogations and blackboard demonstrations. Field trips and the observation of industrial processes in action in neighboring shops had been discontinued. These changes were made necessary by the increased attendance at the school.

At the University of Illinois the instruction in theory was given by lectures and recitations from textbooks combined with the use of plates and models. This was in a way coördinated with shopwork, in that machinery planned in the drafting room was actually constructed in the shops. Much of the early equipment, including an eight horse power steam engine, was constructed by the students in this way. Opportunities for manual labor for pay were offered the students, and many of them earned enough to meet their expenses by making furniture and apparatus in extra hours of shopwork. A chemical laboratory was part of the earliest equipment.

At the Massachusetts Institute there was no shopwork until 1877. The lecture-recitation method of instruction was used in all class work, but this was supplemented by laboratory work in physics and mechanical engineering. The first laboratory for undergraduate instruction in physics was opened here by Professor E. C. Pickering in 1869. The organization and many of the experiments he devised are still used in physics laboratories. The teaching was necessarily very like that in other colleges because all the professors had been trained in existing schools devoted mainly to literary studies.

Chapter III

THE STRUGGLE FOR RESOURCES AND RECOGNITION

The Rensselaer Institute began work in 1824 in a rented house with several hundred dollars worth of equipment, all of which was supplied by the Hon. Stephen van Rensselaer. There were 25 students the first year, each of whom paid $36 tuition, and these fees were paid to the two professors as their remuneration. During the first eight years the founder paid about half the cost of maintenance—a total of $22,000. By that time the value of the equipment had increased to $4000. For twenty years work was conducted in rented quarters. Finally, in 1844, a house and lot were given the school by the city of Troy on condition that a fund equal to the value of the property be raised for maintenance. For this purpose Mr. William P. van Rensselaer gave $6500, and $1150 was raised by subscription to build a chemical laboratory. That year there were 75 students, the tuition was $40 a year, and the total value of the plant was appraised at $15,850.

In 1850 the course was lengthened to three years and the tuition raised to $60 a year. Tuition was increased to $100 in 1857, to $150 in 1864, and to $200 in 1866, at which figure it still remains. In 1851 the state gave the institution $3000 and ten years later $3750, for general purposes. After the fire that destroyed the buildings in 1862, the state gave $10,000 to help rebuild, and this was increased by a further grant of $15,000 in 1868. From 1846 to 1854 the school was classed as an academy by the state Board of Regents and as such received $744 in all as its share of the literature moneys distributed to the academies of the state. These figures represent the entire support granted by the state, a total of $32,494.

From these facts it appears that prior to the beginning of the Civil War this institution owed its existence almost wholly to private benefactions and to the devoted services of its staff, whose enthusiasm and self-sacrifice made the continuance of the work possible with meagre equipment and slender resources. The experience of other schools of this period was similar. At Yale the scientific school was started in 1847, when Professors Silliman and Norton opened a laboratory for practical instruction in the application of science to the arts of agriculture. Professor Norton was permitted to hold the chair of agricultural chemistry on condition that he should draw no salary; this entire enterprise was housed mainly in the chapel attic until 1860, when Joseph E. Sheffield supplied the funds needed to place it on a permanent footing. The Lawrence Scientific School at Harvard was more fortunate in that its early financial support was assured by the gift of Mr. Abbott Lawrence in 1847. The engineering department at the University of Michigan was the one state-supported school of engineering before 1860, but no engineering degrees were granted there until 1861.

Science and engineering in America owe a great deal to the Rensselaer Polytechnic Institute. Founded at a time when the great masses of the people knew little about science and cared less, it quietly and persistently trained teachers and engineers who diffused scientific information and built many of the railways, roads, and bridges that were essential to the success of the industrial evolution. By 1860 it had graduated 318 men, while from the West Point Military Academy, for many years the only other school for scientific training, but 200 of the graduates entered engineering before 1860. The Lawrence School at Harvard graduated 49 men before the Civil War, in the face of an unconcealed disdain on the part of the regular faculty.

It is a very striking fact that before the Civil War so little progress was made in the establishment of schools of science. Altho there were many far-seeing men who urged the need of them in memorials, addresses, and petitions to legislatures, there was little action before 1860. But a great change occurred during the strife and turmoil of battle. Congress passed the Morrill Act in 1862, thereby creating in each state a fund for the establishment of a college "for the liberal and practical education of the industrial classes in their several pursuits and professions in life." In 1861 the Massachusetts State Legislature granted a charter and a tract of land to the Massachusetts Institute of Technology, and in four years over $100,000 had been raised by subscription for a building, and the school had opened for work. The School of Mines at Columbia (1864), the Thayer School at Dartmouth (1867), Cornell University (1867), the Worcester Polytechnic Institute (1868), were established at this time. In addition the states of Illinois, California, Iowa, New York, New Jersey, Maine, Michigan, New Hampshire, Pennsylvania, Tennessee, Vermont, and Wisconsin accepted the terms of the Federal land grant of 1862 before 1870.

But altho after the Civil War money began to flow toward the support of technical education, the financial struggles of the schools were by no means ended. At the Massachusetts Institute in 1868, in spite of stringent economy, the total income of the school was $34,230 and the total expense $42,650. The deficit had to be made up by subscription among the friends of the project. At this time the tuition was $100 for the first year, $125 for the second, and $150 each for the third and fourth. But the total cost per student per year was $250. At Harvard it was then $180, at Yale $126, at Columbia $115, at Brown $178, at Amherst $80, and at the University of Pennsylvania $42. At the new Illinois Industrial University, with a total income in 1869 of $35,000 and 156 students, it was $224, and there were no tuition fees. In other words, the schools soon found that instruction in science was not only new, but more expensive than regular college teaching, because of the relatively high cost of laboratory work and the small number of students.

In the thirty years from 1870 to 1900 the schools slowly grew stronger and more secure. The plant at Illinois increased in value from $186,000 in 1870 to $1,300,000 in 1900, or at the average rate of $37,000 a year. At the same time the annual income increased from $35,000 to $483,000, or at the average rate of about $15,000 a year. The student increase during this period was from 156 to 1756, the average rate being 53 per year.

The complete figures for the typical schools, compiled from the early records and the Reports of the United States Bureau of Education for 1900 and 1916, are given in the following table:

VALUE OF PLANT

	1870	1900	1916	*Increase* 1870–1900	*Increase* 1900–16	*Increase per year* I 1870–1900	*Increase per year* II 1900–16	*Ratio* $\frac{II}{I}$
ILLINOIS	$186,000	$1,300,000	$5,152,000	$1,114,000	$3,852,000	$37,000	$240,000	7
MASS. INST.	400,000	911,000	6,778,000	511,000	5,867,000	17,000	367,000	22
RENSSELAER	50,000	240,000	1,521,000	190,000	1,281,000	6,300	80,000	12

ANNUAL INCOME

	1870	1900	1916	*Increase* 1870–1900	*Increase* 1900–16	*Increase per year* I 1870–1900	*Increase per year* II 1900–16	*Ratio* $\frac{II}{I}$
ILLINOIS	$35,000	$483,000	$2,209,000	$448,000	$1,726,000	$15,000	$108,000	7
MASS. INST.	45,000	348,000	817,000	303,000	469,000	10,100	29,300	3
RENSSELAER	19,000	49,632	225,000	30,000	175,000	1,000	11,000	11

NUMBER OF STUDENTS

	1870	1900	1916	*Increase* 1870–1900	*Increase* 1900–16	*Increase per year* I 1870–1900	*Increase per year* II 1900–16	*Ratio* $\frac{II}{I}$
ILLINOIS	156	1,756	5,523	1,600	3,767	53	235	4
MASS. INST.	167	1,178	1,816	1,011	638	34	40	1.2
RENSSELAER	125	250	545	125	295	4	18	4.5

From these figures it appears that the resources and attendance increased steadily but moderately during the period from 1870 to 1900. Since 1900 the development has not only been rapid; but the buildings, equipment, and expenditures have increased much more rapidly than the number of students. Because of this the total expenditure per student per year has practically doubled since 1900, and every institution in the country is finding it yearly more difficult to live within its income.

The above figures, while as trustworthy as any that can be obtained, are not accurate to within 5 per cent or so. They, however, indicate the general drift clearly enough. In the decade from 1871 to 1880 private benefactions to education averaged $6,000,000 a year. In the past decade they have averaged $26,000,000 a year. In like manner total expenditures for education in the United States have increased from about $75,000,000 a year in 1870 to $240,000,000 in 1900 and to nearly a billion in 1916. The yearly increase up to 1900 was about $5,500,000; since then it has been $48,000,000, or nine times as great.

This growth of the engineering schools in size and resources has been closely paralleled by the development of the engineering profession and of the manufacturing activities of the country. As has been pointed out (page 5), the elevation of the mechanic arts to the rank of a learned profession has always been one of the conscious aims of instruction in applied science. This aim was very vague indeed when the Rensselaer Polytechnic Institute was founded, for at that time there was no engineering profession to define professional standards as a guide to the schools.

The first effort toward a more specific definition of the profession was made in 1839 by Benjamin Latrobe, John F. Houston, Benjamin White, and others, when they tried to establish a national society of civil engineers. This effort was not successful. The present American Society of Civil Engineers was established in 1852 and held its first national convention in 1869. The mining engineers attained this same degree of professional consciousness in 1872, when the American Institute of Mining Engineers was founded. The American Society of Mechanical Engineers was established in 1883, and the American Institute of Electrical Engineers in 1884.

The Census Reports are no more satisfactory concerning engineering than are the Reports of the United States Bureau of Education (page 17). The Report for 1850 lists 512 civil engineers. In 1860 the corresponding entry is 27,437 civil and mechanical engineers, with a footnote stating that this includes stationary engine and locomotive engineers. In 1870 the heading is "electricians, engineers (civil, etc.), and surveyors 7,374." Under this heading the number in 1880 is given as 8261; in 1890 it is 43,239, and in 1900 it has increased to 93,956. The several branches of the profession are recognized for the first time in the 1910 report, which enumerates 14,514 engineers (mechanical), 6930 mining engineers, 52,033 civil engineers and surveyors, and 135,519 electricians and electrical engineers—a total of 208,996. Probably not more than 80,000 of these engineers enumerated by the census could qualify for membership in any of the professional societies mentioned, which now have about 30,000 members. Recently a number of new engineering societies have been organized, representing cement, automobiles, electric light, electric traction, etc. The total membership in all the societies having headquarters in the Engineering Societies Building in New York is about 53,000.

The rate of growth of the engineering societies is shown in the following table:

	Founded	*Membership*		*Increase*		*Increase per year*		*Ratio* $\frac{II}{I}$
		1900	1916	*Origin*-1900	1900-16	I *Origin*-1900	II 1900-16	
Civil Engineers	1852	2227	7909	1984 (*since 1870*)	5682	66	355	5
Mining Engineers	1872	2661	5234	2661	2573	95	161	1.7
Mechanical Engineers	1883	1951	6931	1951	4980	114	311	2.8
Electrical Engineers	1884	1273	8212	1273	6939	80	434	5

These figures indicate that the professional societies, like the schools, have grown much more rapidly since 1900. This probably does not result so much from mere increase in the total number of engineers in the country, as from an awakening and expansion of professional consciousness. The establishment of the Engineering Foundation in 1915, the coöperation of the engineering societies with the National Academy of Science in the National Research Council, the bill to charter an American Academy of Engineers introduced into Congress in 1917, and the recent discussion of the status of the engineer also indicate that the engineers have only just reached that state of professional consciousness where they are able to define their status among the learned professions. This definition is now in process of formulation; and until it is announced, it is unreasonable to expect the statisticians at the Census Bureau or the Bureau of Education to distinguish clearly between the professional civil engineer and the surveyor or between the electrician and the electrical engineer.

The part played by the colleges in this development of professional spirit may be estimated from the fact that the various schools had graduated 866 engineers up to 1870, or less than one-ninth of the 7374 practising engineers in the country at the time. As indicated on page 7, the total number of engineering degrees granted in the United States has been approximately 55,000. Since a number of these graduates have died and perhaps a fifth of them have gone into other lines of work, it is safe to say that there are not more than 40,000 graduates of American engineering colleges in engineering practice to-day. If the number of professional engineers is approximately 80,000, it follows that now possibly about one out of every two is a college graduate. Since this ratio was only one in eight or nine in 1870, the magnitude of the contribution of the schools to the development of the profession is obvious.

The growth of the second powerful influence on the development of the engineering schools—the manufacturing industries—is indicated by the following facts: The total value of manufactured products in the United States in 1870 was 3400 million dollars. In 1900 the value was 13,000 million dollars, and in 1916 it was 32,200 million dollars. The increase in value of manufactured products for the period 1870–1900 was therefore 9600 million dollars, or at the average rate of 320 million a year. In the sixteen years from 1900 to 1916 this increase was 18,200 million dollars, or at the average rate of 1138 million a year. Hence, like the schools and the professional societies, the manufacturing industries have developed much more rapidly in the twentieth century than in the nineteenth.

The attitude of these industries toward the college-trained man is indicated by the fact that of the 4622 technically trained men now employed by 98 representative manufacturing establishments 1992, or 43 per cent, have engineering degrees. The highest ratio is in the field of metal refining, where 87 per cent of the technical men are college graduates. The lowest ratio is in the automobile trade, where only 49 out of 186, or 24 per cent, are college-trained men. In shipbuilding the ratio is 48 per cent, 359 out of 735, and in machinery and machine tools it is 41 per cent, 836 out of 2043. In response to the question "Do you employ men graduated from engineering colleges in preference to men trained mainly thru practical experience?" 60 out of 120 firms answered "yes;" 40, or one-third of the number, answered "no;" and 20, or one-sixth of the whole number, expressed no preference.

It is difficult to interpret the interplay that has been going on among industry, science, and engineering. At the close of the Civil War science had but scant recognition either in educational institutions or among the masses of the people. Now it has assumed a commanding position because of the transformations it has wrought in the daily life of every one thru its varied and fruitful inventions. In this development there has been no regular procedure, no well-defined organization. It has been a matter of independent action and individual effort. Sometimes it was the college professor of science, pure or applied, sometimes it was the inventor or the professional engineer, and sometimes it was the manufacturing industry that took the initiative, conceived the new idea, or made the new discovery, and sought the assistance of the others in realizing it in practice. Now evidences are multiplying to show that the time has come for a clearer definition of the relations among research, instruction, engineering practice, and industrial production. How to coördinate these elements most effectively is a large and pressing problem. Further consideration of the meaning of this problem to the engineering schools is given in Chapter XII.

Chapter IV

THE DEVELOPMENT OF THE ENGINEERING CURRICULUM INTO ITS PRESENT FORM

In the fifty years that have elapsed since the curricula described in the second chapter were established a number of striking changes have taken place. The general nature of these changes is indicated in the following tables, which give the data for two of the schools selected as typical. The Rensselaer Polytechnic Institute has been omitted because its early programs do not give the number of hours per week assigned to the various subjects.

Entrance Requirements

Massachusetts Institute of Technology

1870	1914	
Arithmetic		
Geography		
Algebra to quadratics	Algebra A	160 hours
	Algebra B	160 hours
Plane geometry	Plane geometry	160 hours
	Solid geometry	160 hours
English grammar	English composition	
	English literature	
	Physics	
	French	240 hours
	German	240 hours
	Electives	

University of Illinois

Arithmetic		
Geography		
Algebra to quadratics	Algebra A	1 unit[1]
	Algebra B	½ unit
Plane geometry	Plane geometry	1 unit
	Solid and spherical geometry	½ unit
English grammar	English composition	1 unit
	English literature	2 units
United States history	Physics	1 unit
	Electives	8 units

In 1867 admission was by examination. Graduation from high school was not mentioned, the sole requirement being ability to meet the tests and an age limit of 16 years. Admission is still by examination at the Massachusetts Institute of Technology, while at the University of Illinois it is now mainly by certificate from accredited high schools.

It will be noted that arithmetic and geography are no longer required, probably because it is assumed that they have been satisfactorily completed in the grammar school.

[1] The unit is generally defined as one-quarter of a year's work in a secondary school.

The number of examinations (or subjects required) has increased from 5 or 6 to 8 or 10. The amount of algebra, geometry, and English required has been increased by from 50 to 300 per cent. The content and methods of instruction in the various high school units have also been carefully defined and standardized by the College Entrance Examination Board, the National Educational Association, and several other associations in which colleges and secondary schools are represented.

These changes are the direct result of the development of the public high schools. Altho the average age of entrance to college has remained constant at about 19 years, the present freshman has had more instruction and more highly systematized instruction in more subjects than was possible before the recent striking development of secondary education.

At present all but 4 of the 126 engineering colleges require at least 14 units for admission without condition. These four are tax-supported institutions in states where the public school systems have not developed to the point where the requirement of four years of preparatory work would be justified. They are raising their requirements as fast as local conditions permit. Forty of the schools still advertise that they accept students with two or three units of conditions. All admit either by certificate from accredited high schools or by examination excepting the Massachusetts Institute and the Sheffield Scientific School, which admit by examination only. West of the Alleghenies entrance examinations are rare.

The number of units specifically prescribed for admission varies from 5 at the North Carolina College of Agriculture and Mechanic Arts, to 13 at Yale and George Washington University, or even to 14 at Notre Dame University. Half specify 10 or less, and half specify more than 10. All agree in demanding English and mathematics, the amounts varying from 2 to 4 units. In English nine-tenths of the schools regard 3 units as standard, while in mathematics six-tenths have settled upon 3 as standard, half of the remainder requiring more and half less. History is specifically required by 71 per cent of the schools and one science (physics or chemistry) by 73 per cent. One-third, mostly land grant colleges and state universities, require no foreign languages for admission.

The nature of the changes in the distribution of time in the curriculum itself is indicated by the following typical cases. The unit is the semester-hour.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mechanical Engineering

	1867	1914	Per cent of Total Time 1867	1914
Foreign languages	31	7		
English	14	8		
History	3	4		
General studies	0	12		
	48	31	31	18

	1867	1914	*Per cent of Total Time* 1867	1914
Mathematics	16	17		
Chemistry	8	17		
Physics	12	14		
Geology	2	0		
Mechanics	4	13		
	42	61	27	36
Drawing and descriptive geometry	49	17		
Mechanical engineering	10	0		
Machinery and motors	4	0		
16 specialized courses in M. E.	0	63		
	63	80	42	46

The most notable changes in the mechanical engineering curriculum of the Massachusetts Institute of Technology, as noted above, are:

The reduction of the foreign language requirement from 31 to 7 credit hours. This is partly a result of better language work in preparatory schools.

The apparent reduction of the English requirement from 14 to 8 credit hours. In interpreting this fact it must be noted that in 1867 the study of political economy, the United States Constitution, and some history of civilization were included under the head of English. Subjects like these are now provided for in the 12 credit hours of general studies. On the whole, however, the time given to these "humanities" has been reduced from 31 per cent to 18 per cent of the total.

In the science group, chemistry has increased from 8 to 17 credit hours, and mechanics now gets 13 instead of 4. This latter increase is noteworthy because the fundamental principles of mechanics have not changed materially in the past fifty years. Some of the additional time is devoted to laboratory work in applied mechanics, strength of materials, etc. Mathematics and physics retain practically the same time allowance. The time given to science has in general increased from 27 per cent to 36 per cent.

The technical subjects have been given more time (from 63 to 80 credit hours), altho their percentage has increased but little (42 to 46). They have, however, been specialized to a high degree. The only technical subjects mentioned in the program for 1867 were drawing (47 hours), mechanical engineering (10), machinery and motors (4), and stereotomy (2). To-day the mechanical engineer must take drawing (17 hours), heat engineering (7), mechanism (6), boiler design (3), engineering laboratory (3), electrical engineering (7), machine design (8), dynamics of machinery (2), hydraulics (5), factory construction (3), power plant design (4), foundations (1), refrigeration (1), heating and ventilating (1), and shopwork (10).

This increasing specialization has not been confined to the subject-matter of each curriculum. In 1886 the civil engineering curriculum was divided into three sub-specialties, civil engineering, railroad engineering, and topographical engineering. The following year mechanical engineering was divided into marine engineering, locomotive engineering, and mill engineering. As a result, the six different curricula of 1867 have now expanded into more than twenty. Fifty years ago the work of the first two years was the same in all six curricula; now specialization begins in the middle of the first year. Then a student carried only four or five courses at one time; now he carries from eight to thirteen.

The following table gives the distribution of time among the three main divisions of the materials of instruction for two curricula in the two typical schools together with the average for all 126 schools. The figures are per cents.

1867	*Languages Humanities*	*Mathematics Sciences*	*Drawing Engineering*
Illinois C. E.	25	33	42
Illinois M. E.	24	40	36
Massachusetts Institute of Technology C. E.	29	29	42
Massachusetts Institute of Technology M. E.	31	27	42
Average	27	32	41
1914			
Illinois C. E.	12	30	58
Illinois M. E.	14	33	53
Massachusetts Institute of Technology C. E.	17	35	48
Massachusetts Institute of Technology M. E.	18	36	46
Average	15	34	51
Average (all schools)	19	29	52

There is no agreement as to what percentage of time should be devoted to each of these main groups of subjects. The percentage devoted to professional work varies from 25 at Northwestern, or 30 at Johns Hopkins University, to 70 at Cornell, or even to 85 at the Michigan College of Mines. Similarly there is no accepted proportion for individual subjects like calculus, which varies from 52 hours at Rensselaer to 216 hours at the University of Florida. The requirement in languages in college varies from zero at Leland Stanford, the University of Virginia, and Cornell, to 408 hours (18 per cent) at the Sheffield Scientific School at Yale, or to 594 hours (18 per cent) at the Virginia Polytechnic Institute. The total number of hours of assigned work required for graduation varies from 2000 to 3800, and the number of required credit hours per week varies from 16 to 28.

At several of the schools visited efforts are being made to adjust the requirements of the several courses in such a way that a student will be able to accomplish the work in 50 hours a week, including class work, laboratory work, and outside preparation. As a matter of fact few students succeed in keeping up to grade without spending much more than this on their work. If a student is able to keep within the limit, he has, when he is carrying thirteen courses, on the average 3 hours, 50 minutes, and 46.15 seconds per week for each. Rensselaer is the only school among those visited that limits the students to three subjects at any one time. There each subject is pursued intensively for a stated period that varies from one to fourteen weeks. Thus the freshman begins work with chemistry, drawing, and French. At the end of eight weeks his three subjects are algebra, drawing, and French. In the second term he begins with trigonometry, French, and steam engineering, which is changed at the end of five weeks to gas analysis, French, and physics. By this means, altho he carries but three studies at one time, he actually completes from ten to eighteen different subjects each year.

There is almost unanimous agreement among schools, parents, and practising engineers that at present the engineering curriculum, whatever its organization, is congested beyond endurance. It is obviously absurd to require from the student more hours of intense mental labor than would be permitted him by law at the simplest manual labor. Yet on all sides the pressure of topics and subjects that have become important because of the extraordinary growth of science and industry is constantly increasing. In 1870 a student might choose his specialty at the end of his second year; now he must decide in many cases in the middle of his first year. Formerly the choice lay among civil, mechanical, and mining engineering; now the selection must be made from aeronautical, agricultural, architectural, automobile, bridge, cement, ceramic, chemical, civil, construction, electrical, heating, highway, hydraulic, industrial, lighting, marine, mechanical, metallurgical, mill, mining, railway, sanitary, steam, textile, telephone, topographical engineering, and engineering administration. No one school offers curricula in all of these specialties. But all are offered somewhere, and enough are given at every school to render the selection during the freshman year of his life's specialty a peculiarly difficult matter for the student.

From the wide variations in the amount of time required for completing the course and the great diversity of ways in which the schools have met the demands of increasing specialization in industry it is clear that they have reached no general agreement as to how to deal with the problem. Each has sought to adjust itself as best it could to the immediate demands in its locality, and has added specialized courses as the need for them appeared. But tho there are many variations in the details of curricula at the several schools, all have remained true to the original conception of the early curriculum; namely, that instruction in the general principles of science and in the humanities should precede instruction in the various technical specialties. In nearly all curricula the work of the freshman year consists of chemistry, mathematics, English, foreign languages, and drawing. The work of the sophomore year, while not so well standardized, very generally contains calculus, physics, some language study, and drawing, with here and there a few of the engineering courses. The junior and senior years are filled to overflowing with specialized technical courses.

The present curricula are thus the natural result of two well-defined influences; namely, the original curriculum that was imported from France in 1849 by Professor

B. F. Greene of Rensselaer, and the phenomenal expansion of science and industry. Meanwhile, two other influences have been gradually developing—the engineering profession and the science of education. The bearing of these on present practices is discussed in the later chapters.

Since the plan on which this study was carried out did not contemplate a complete survey of engineering schools or a grading of them into classes as good, bad, or indifferent, only twenty typical schools were visited. The examples in the following chapters are therefore drawn in the main from these schools, selected not because of their geographical location, but because they seemed representative of all types of engineering college. The author wishes here to express his appreciation of the cordial manner in which all college presidents and teachers coöperated in securing all the information sought and in frankly discussing mooted points. The twenty schools visited were the following:

The United States Military Academy, West Point, N. Y.
Rensselaer Polytechnic Institute, Troy, N. Y.
Massachusetts Institute of Technology, Cambridge, Mass.
Stevens Institute, Hoboken, N. J.
Carnegie Institute of Technology, Pittsburgh, Pa.
Columbia University, New York, N. Y.
Tufts College, Tufts College, Mass.
Worcester Polytechnic Institute, Worcester, Mass.
Virginia Polytechnic Institute, Blacksburg, Va.
Purdue University, Lafayette, Ind.
Pennsylvania State College, State College, Pa.
Cornell University, Ithaca, N. Y.
Sheffield Scientific School, Yale University, New Haven, Conn.
University of Pennsylvania, Philadelphia, Pa.
University of Virginia, Charlottesville, Va.
University of Pittsburgh, Pittsburgh, Pa.
University of Illinois, Urbana, Ill.
University of Wisconsin, Madison, Wis.
Ohio State University, Columbus, Ohio.
University of Cincinnati, Cincinnati, Ohio.

Chapter V

METHODS OF ADMINISTRATION IN ENGINEERING SCHOOLS

The final control of American Engineering Schools, as of the colleges and universities, is vested in a board of trustees or regents. In the case of state institutions the members of the governing board are usually appointed by the state governors, while in independent institutions they are self-elected for long terms. Generally the regents or trustees are citizens who have won distinction in either professional or industrial life. In a few cases a limited number of members of the faculty are also members of the board; but as a rule all communication between the faculty and the board is thru the president.

The regents or trustees are charged with the financial management of the schools. They elect the president on their own initiative and appoint or promote members of the faculty on his recommendation. All appropriations, to be legal, must have their sanction, and educational policies framed by the president or the faculty are nominally subject to their veto. This organization places large responsibilities on the president and makes it possible for him to be the dominant influence in the development of a school.

In the early schools the problem of framing and administering the requirements for admission and graduation was relatively simple. At Rensselaer the first faculty had but two members, both chosen because of their sympathy with the educational aims of the institution. Similarly at the Massachusetts Institute, President Rogers surrounded himself with a faculty of nine men who were enthusiastically devoted to him and to the new venture. Prior to 1870 no school had as many as 200 students, curricula were few, and the faculties were so small that a close and intimate coöperation among the members and with the president was everywhere the rule. But with a teaching staff of 260 and 2000 students, the present numbers at the Massachusetts Institute, this direct personal contact among the members of the faculty and between instructor and student is no longer possible. It was easy for Professor Pickering to exert a strong personal influence over every one of the 25 students in his pioneer physics laboratory; but it is impossible for any one to do the same when there are 450 students who need apparatus, attention, and guidance. The increase in number of students from 1500 in 1870 to 33,000 now, in value of plants from about one million dollars to sixty-eight millions, in annual expenditures from about $250,000 to over eleven millions, and in number of professional specialties from four to perhaps forty, has compelled the devotion of a large amount of attention to the organization and administration of the daily routine on which the effectiveness of the school so largely depends.

The regulations and the administrative systems that have been developed at the various schools under the pressure of increasing size and complexity differ widely from one another. All bear evidence of having been shaped to meet local needs under the guidance of individuals of strong convictions. But while it is not possible to classify these systems in well-defined categories, they may be arranged in a series that extends from what may be called the marked military type, on the one hand, thru the autonomous-department type, to the well-defined coöperative type on the other.

The leading characteristics of the military type are exhibited best in the administration of the United States Military Academy at West Point. Since this school is supported from the federal purse, its financial control is vested in Congress, which makes its appropriations for this purpose on the recommendation of the War Department and the Board of Visitors, composed of five senators and seven members of the House of Representatives. The administration of the school is entrusted to the superintendent and the academic board, consisting of the superintendent, the commandant of cadets, and the eleven heads of the departments of instruction. The curriculum framed by this board, the methods of instruction, and the textbooks selected for use are subject to approval by the War Department. The time schedule and the order of instruction in the several courses are determined by the academic board, which also conducts examinations, passes on the merits and proficiency of the cadets, grants diplomas, and makes recommendations for commissions in the army. When considering questions concerning relative standing and promotion, the senior assistant in each department sits with the academic board.

The officers of instruction are detailed to this duty by the War Department. Their number varies from 110 to 120 for 580 cadets. Only the thirteen members of the academic board have any voice in selecting subject-matter and determining methods of instruction. The classes are divided into small sections, usually of twelve each. The ground to be covered each day and even the questions to be asked during each lesson are as a rule determined by the head of the department, who is also required to visit each section frequently in order to ascertain the proficiency and qualifications of the cadets and the manner in which the instructors perform their duty. The assistants seldom serve more than four years, but new appointees are usually required to attend classes and study the methods of instruction for a few months before being placed in charge of sections.

The daily routine of each cadet is rigidly prescribed. He is responsible for some duty every hour, is sure to be called to recite at every class meeting, and is given a numerical grade for every recitation. These grades are reported by every instructor every week, and the roll of the class is arranged each month in the order of the ratings. The division of the class into sections is made according to the relative standings; the twelve cadets with highest standings being assigned to the first section, the next highest twelve to the second section, and so on. The instruction is to a certain extent adjusted to the ability of the several sections, the more difficult investigations and subjects being given only to the higher sections. Assignments after graduation and relative rank when commissioned follow the order of merit at graduation. The maximum number of grade points attainable by a cadet in the four years is 2525; and since these are assigned by a large number of different instructors, the number secured is a pretty accurate measure of the cadet's ability to meet the requirements of the academy. Because of this fact, the grading system is a very real incentive to good work and to the maintenance of the ideals of soldierly honor and obedience to orders which are such effective features of this school.

While military drill and military instruction are required of male students at all the land grant colleges, military methods of administration are little used in engineering schools. Here and there may be found a single department that is administered in a military manner. At the University of Pennsylvania several departments divide their classes into small sections, outline the work for each "section hand," as the instructors have been called, and rotate the instructors among the sections each week. Johns Hopkins University has recently introduced a curriculum called military engineering very similar to that given at West Point, but the methods of administering it do not differ from those used for the rest of the school. The West Point honor and grading systems and West Point discipline, either for instructors or for students, were not found at any of the other schools.

In the great majority of engineering schools the control of the curricula, the regulations for admission and graduation, the time schedule, and the discipline are vested in the faculty, which is composed of all officers of instruction above a specified rank, differently defined at the various schools. All general educational policies, requirements, and rules for students are determined by a majority vote of the faculty and administered by executive officers, deans, and boards or standing committees, usually appointed by the president, tho at several institutions they are elected by the faculty. The number of these committees varies from six to twenty-six. Every voting member of a faculty is subject to service on committees, many of which have to meet weekly and devote much time to their work.

Faculty control generally ends with the adoption of the curriculum and the time schedule. Having determined by majority vote the requirement in hours for each subject, the choice of subject-matter, texts, and methods of instruction in each subject is left entirely to the department concerned. For example, if three hours a week is assigned by the faculty to English, the department of English may use that time in any way it likes. Each department is treated as an expert in its own line, and this departmental autonomy is carefully preserved by common consent. Departments vary in size from three or four members to thirty or forty, and a serious effort is always made to assign each man to work for which he is particularly fitted by temperament, ability, and training. Hence the various phases of the work within a department are usually well coördinated, but the policies and methods of instruction in the different departments of the same school often differ widely from one another. While faculty control is more democratic than military control in that every member of a faculty has a vote on questions of general requirements and policies, it does not produce the unity of aim and effort exhibited at West Point because its jurisdiction ends at departmental boundaries. For this reason, this form of administration is called the autonomous-department type.

When an engineering school is part of a large university, — like Cornell, Ohio State, or Illinois, — which also contains a school of liberal arts, a law school, a medical school, and an agricultural school, it is customary to vest the control of each school in an independent faculty of its own. The departments of English, foreign languages, mathematics, physics, and chemistry are usually organized under the faculty of liberal arts, frequently without representation on the engineering faculty. In such cases engineering students are under the jurisdiction of the faculty of liberal arts for most of their work during their first two years, and the engineering faculty has limited control of the instruction of its students in these fundamental subjects. Under these conditions the four-year course in engineering has no coördinating centre.

The coöperative type of administration has reached its fullest development at the engineering school of the University of Cincinnati, tho both the Sheffield Scientific School at Yale and Stevens Institute are experimenting along analogous lines. At Cincinnati the engineering school has its own departments of English, mathematics, and foreign languages; and the departments of physics and chemistry, tho organized under the faculty of liberal arts, are represented in the engineering faculty by the instructors who teach the engineers. The faculty thus constituted meets every Saturday morning for a systematic study of its educational problems. A syllabus stating the objects, the methods, the subject-matter, and the mechanism of the school as a whole was prepared by the dean and discussed at length by the faculty. After many changes and amendments, the syllabus was finally adopted as an adequate expression of the basic conceptions toward which the school as a whole is working. Each department in turn then presented a similar syllabus setting forth in detail the objects, methods, subject-matter, and mechanism by which it proposed to contribute to the general result. These departmental syllabi were discussed freely by the whole faculty, and approved only when a general agreement had been reached. In this way there has been developed a very effective coördination of effort among the several departments.[1]

The coördination of effort does not end with the agreement on syllabi. By unanimous vote of the faculty no student is finally passed in any subject until he graduates. Each student is graded at the end of each course; but if, after receiving a passing grade in any subject, he shows in a later course that he is weak in that subject, he is sent back to the department in question for more work. For example, the professor of machine design may "flunk" a man in calculus if he cannot use the calculus properly in the work in machine design. Again, all reports prepared for the technical departments must pass the department of English before reaching the department for which they are intended. This coöperation among the departments in the school

[1] A full description of the system, including several of the syllabi, has been published by the United States Bureau of Education in Bulletin 31, 1916, on *The Coöperative System of Education*, by Professor C. W. Park.

is as important an element in the Cincinnati experiment as is the coöperation of the school with the industries. The University of Pittsburgh and the Massachusetts Institute of Technology are coöperating on a part time basis with industries, but their faculties are organized on the autonomous-department plan.

The coöperative type preserves one of the main advantages of the military type in that its jurisdiction extends within departmental boundaries. Since it uses this jurisdiction not for autocratic control but as a means of converting a government by majority vote into a community of effort for the student's good, it also possesses another of the effective factors of the military type, namely, homogeneity of action. When skilfully organized, as at Cincinnati, the engineering faculty is a coördinating centre for the entire engineering curriculum. Nor does it appear to have lost any of the nominal advantages of the autonomous-department type in the way of personal freedom of its members and inspiration for creative work.

CHAPTER VI

STUDENT ELIMINATION AND PROGRESS

Actual Elimination

Method Used

Ratio an expression

ENGINEERING schools as a rule keep accurate account of the number of students in attendance each year in each class. These figures, however, do not show how large the actual elimination is, because a number in every graduating class have pursued irregular courses—have entered with advanced standing or been retarded a year or more. Hence the difference between the number of graduates in any given year and the number of freshmen four years back does not indicate the true mortality. In order to determine this it was necessary at each of the schools visited to pick from the records of the graduating class all students who had entered four years before and proceeded thru without break. The ratio of this number of what may be called regular graduates to the total number of freshmen four years previously is one expression of the manner in which a school is meeting the needs of its locality.

Penn State 50%

Ill.-Wis. 25%

2 yrs.-20 Schools 40%

Heistand's estimate

Further investigation

Improvement

Only one of the schools visited already knew how large its elimination is when counted in this way. Among this selected list of schools the lowest mortality was found at Pennsylvania State College, where just half of the freshmen went thru regularly and graduated in four years. The highest losses were found at the Universities of Illinois and Wisconsin, where only about one-quarter of those admitted as freshmen graduate regularly on schedule time. The figures vary from year to year at every school, so that no fixed figure can be given for any institution; but from the counts made for two years at twenty schools it is clear that less than 40 per cent of all freshmen at engineering schools complete the course in the allotted time. While this record is sufficiently striking, it is better than it was in the early days. Then in some cases the elimination was as high as 91 per cent and the average was nearer 75 than 60. This change for the better is in large measure the result of the increased efficiency of the secondary schools.

While it is interesting to compare the elimination of 66 per cent at the Massachusetts Institute, which admits only by examination, with the elimination of 75 per cent at Wisconsin or Illinois, which admit almost wholly by certificate, it is not safe to draw any conclusions as to the relative merits of the two methods of admission. Elimination depends on too many other variable factors, such as physical health, family conditions, financial resources, college spirit, the appeal of the college work, and the friendly personal interest of the faculty. For example, the date of Dean Burton's appointment as counselor to freshmen at the Massachusetts Institute is recorded by a sharp drop in the freshman mortality figures. Because of the complexity of the problem it is perhaps not surprising that the schools have no records as to the reasons for withdrawal.

Nearly half of the elimination takes place in the freshman year and about one-quarter more in the second year. During these years almost all of the time is spent on Eng-

Our experience - 3 yrs - 50% promoted

lish, mathematics, foreign languages, chemistry, and physics, and little opportunity is afforded for contact with real engineering projects. Hence many engineering students are eliminated before they have a chance to show their ability at their chosen profession. At one of the schools several cases were found where engineering students had been eliminated during the freshman year for failure to meet the demands of the department of German. At another English literature was a fertile source of discouragement for freshmen. A large amount of pertinent information concerning the success of school administration and instruction may be secured from a study of the reasons why students leave engineering schools, especially since many who do leave before graduation persist in engineering and make a success of it.

Eliminated before tested.

many of those who fail succeed

The variations of the average grades of a group of students thru their four years of work supply an interesting basis on which to judge of student progress and the adaptation of the work to student needs. The following table presents for each of the four years the weighted average grades[1] of a group that entered regularly, progressed normally, and graduated on time at the several schools named:

Average grades interesting

Institution	*Cases*	*Fr.*	*So.*	*Jr.*	*Sr.*
University of Illinois	64	86.9	84.1	83.7	83.2
University of Virginia	17	86.0	84.0	82.0	85.0
Purdue University	51	84.7	83.2	80.7	81.6
Rensselaer	22	83.7	81.7	82.5	83.7
University of Wisconsin	47	84.5	83.3	83.2	86.3
Pennsylvania State	54	80.6	80.4	78.4	79.6
Virginia Polytechnic	48	79.6	77.0	77.3	87.3
Stevens	51	78.1	73.4	75.5	74.0
Cincinnati	19	77.4	76.5	74.9	76.7
Columbia	56	77.2	76.2	75.8	74.9
University of Pennsylvania	55	74.5	72.0	70.0	71.5
Ohio State University	46	72.0	71.0	70.6	71.2
Yale (Sheffield)	79	67.0	65.2	68.2	
Massachusetts Institute	67	66.8	64.7	65.6	64.0
Cornell (Sibley)	40	75.2	72.9	73.2	73.9
Cornell (C. E.)	30	76.3	76.0	72.1	75.2
Tufts	39	72.0	68.0	70.0	73.0
Average	785	76.9	74.9	74.8	76.9

Average age of graduation 22 years, 11 months.

Corresponds to our data. In L & S.

In every case the standing of this random group of the regular graduates is higher in the freshman than it is in the sophomore year. In the general average for the 785 cases studied the drop of 2 points persists thru the junior year and is recovered in the last year. The phenomenon is general, altho some schools exhibit it more markedly than do others.

While several interpretations of the meaning of this sag in the average grade curve are possible, its cause may be located statistically by noting in what subjects the

[1] The weighted average is found by multiplying each grade by the number of credit hours it represents, adding the products, and dividing by the total number of credit hours for the year.

students had the greatest number of low grades in those years. For this purpose thirty or more records of regular graduates were taken at random and the number who received low grades in each subject was counted for each school. The meaning of the term "low grade" was determined at each institution from a study of the local grading system. At schools that grade numerically with 60 as the pass mark, like Virginia Polytechnic Institute, Stevens Institute, and Cornell University, all marks below 70 were counted as low. Thus, for example, at Stevens Institute out of 51 cases studied, 31 had at least one grade below 70 in physics and the average mark in that subject for these thirty-one students was 63.2. In calculus 26 had received grades below 70, the average being 63.1, and so on. When 70 was the pass mark, as at the Universities of Illinois and Wisconsin and Pennsylvania State College, marks below 80 were counted. At the Massachusetts Institute of Technology, where 50 is the pass mark, L, which stands for a rating between 50 and 60, was considered a low grade. At Sheffield Scientific School and Rensselaer Polytechnic Institute, which grade on a scale of 4 with 2 as the pass mark, marks below 2.4 were counted. The grading systems of the University of Pennsylvania, Ohio State University, and Purdue University could not be used for this purpose because they recognize only three grades, A, B, and C, above pass mark and the lowest grade covers too wide a range. At Ohio State University a new grading system with five steps between pass and 100 has recently been introduced.

Took 30 records at random

12 schools.

The table on page 35 gives the results of this count for twelve schools. Every student whose record was counted was a regular student who had entered without conditions, had passed thru normally in the regulation time, and had received his degree. The low marks of the 60 per cent who were "weeded out" are not included; if they had been, the percentages would be much higher. The figures in the table are therefore a fair statement of the results achieved by a school under the most favorable conditions.

Why weeded out

Taken in connection with the facts of elimination, these figures show that out of every 1000 freshmen not more than 400 graduate in the specified time, and that half of these just "get by" in physics, calculus, and mechanics. The percentage of low grades is about the same in English and modern languages when these subjects are required. This means that out of every 1000 who are admitted only about 200—20 per cent—adapt themselves creditably to the requirements of the schools in these so-called "fundamentals."

1/2 "get by"

20% satisfactory work.

The two tables make it clear that the drop in the average grades occurs when physics and calculus with an average low grade record of 49.5 per cent replace chemistry and freshman mathematics with an average low grade record of not over 25 per cent. It is not possible to give this last percentage exactly because the freshman mathematics courses are not comparable; but the low grade counts in advanced algebra, trigonometry, and analytics are all below 20 per cent. Altho the third year program and courses differ so much from one another that the figures from various schools cannot be com-

1st yr {math chem.
2nd yr drop: cause {Physics calculus

NUMBER AND PERCENTAGES OF LOW GRADES IN PARTICULAR SUBJECTS

Institution	*Number of Cases*	*Physics*	*English*	*Modern Languages*	*Calculus*	*Mechanics*	*Chemistry*	*Descriptive Geometry*
1	67	43-64%	37-55%	38-57%	22-32%	21-31%	20-29%	13-19%
2	79	40-51	47-60	51-64	48-61	47-60	31-40	26-33
3	51	31-60	11-21	4-8	26-51	26-51	11-21	21-41
4	48	21-47	37-77	34-69	13-29	20-42	7-14	5-10
5	43	30-69	not required	not required	32-74	28-65	14-32	16-37
6	54	38-70	not required	not required	33-61	35-65	15-28	21-40
7	19	10-52	10-52	6-31	9-47	13-68	11-58	4-21
Wis 8	46	13-28	13-28	16-35	18-40	25-54	7-15	6-13
Ill 9	64	24-37	31-48	not required	27-42	27-42	14-22	4-6
10	22	15-68	16-72	7-33	15-70	5-23	15-70	10-45
11	44	13-30	7-16	not required	22-50	24-55	12-27	5-11
12	84	39-47	40-48	48-57	33-39	49-58	44-51	34-40
Totals	621	317	249/534	198/416	298	330	201	165
		51.0%	46.6%	47.5%	48.0%	53.1%	32.3%	26.5%

pared, it is fairly evident that the mechanics, which is common to all and which has a low grade record of 53.4 per cent, is largely responsible for the continuation of the low average grade thru the junior year. 3rd yr Mechanics

While many professors regard a high percentage of low grades as proof of efficient teaching, experience has proved that an excessive number of low grades in some particular subject in the records of regular graduates is a sign of some trouble that can usually be removed by a little attention. For example, 80 per cent of the regular graduates of 1914 in Cincinnati had low grades in History 50. This course had been introduced the previous year to give a broader outlook. It consisted of a rapid study of geologic evolution, of biologic evolution, and of the evolution of civilization given by the respective heads of the departments of geology, biology, and history in the Faculty of Arts, Literature, and Science. The first year it proved a great success, and the engineering students in the class of 1913 gathered much information and inspiration from it. But the class of 1914 had much trouble with it until it was discovered that it had been turned over to a young instructor who was drilling the class on Guizot's *History of Civilization* by the textbook-recitation method. The course was promptly dropped and the students absolved from the requirement by the engineering faculty.

Since employers regard college grades as precarious guides in selecting men for jobs, an effort was made to find out whether the fact that about half the graduates of engineering schools have received low grades in physics, calculus, and mechanics means that half the graduates are on that account low grade engineers or not. The direct method of doing this would involve tracing the later careers of those who received the low grades to see if they were relatively less successful than those who ranked high in these fundamental subjects. This method is impracticable because there is as yet no valid definition of what constitutes success in engineering. There are, however, a number of large industrial firms that employ several hundred college graduates each year and keep records of their accomplishments. A comparison of the records of the same men in college and in industry would indicate how close the correlation between them is.

Thru the courtesy of Mr. A. L. Rohrer of the General Electric Company of Schenectady, copies of his records of the 168 graduates in their employ from the class of 1913 of all the schools visited were secured. On these records each man was rated by each of the foremen under whom he worked as A, B, or C in each of the five qualities, Technical ability, Accuracy, Industry, Ability to push things, and Personality. Thru the courtesy of the schools copies of the full college records of these same men were secured. An extended study of these two sets of records by Professor E. L. Thorndike of Columbia showed that the correlation between the two was very slight; that is, that ability to secure high grades in college was no indication of ability to meet the requirements of the General Electric Company. On the other hand, the college grades signify something, since the grades for the senior year correlate closely with the average grade for the entire course, showing that ability to secure high grades in college is a stable and permanent characteristic of an individual. A similar study was made thru the courtesy of Mr. C. R. Dooley of the Westinghouse Electric and Manufacturing Company of Pittsburgh of a group of 40 college graduates in the employ of that company. The results were practically the same.

While these studies have not yet settled the problem, they serve to define it more clearly. The facts are that half of the college graduates are rated low in the fundamental subjects by their college instructors, and that college grades show little correlation with the ratings of two large industrial companies that "take on" several hundred college graduates each year.

Prof Smiths investigation — 1800 - 15 yrs — period 45 yrs.

Chapter VII

TYPES OF INSTRUCTION IN ENGINEERING SCHOOLS

The method of instruction employed at Rensselaer during the first five years (1824–29) was new in America, tho it resembled the methods inaugurated in 1806 by Pestalozzi in the Fellenberg School at Hofwyl, Switzerland (page 9). It was designed by the first senior professor, Amos Eaton, who was a graduate of Williams College and had done graduate work with Silliman at Yale. At no other school was the student given the place of the teacher and compelled to rely on his own resources in preparing subjects for presentation to his classmates. The observation of industrial processes as the basis for class discussion and laboratory problems which led by inductive processes to general principles after the manner of real scientific investigation were at this time unique in elementary instruction. No other school treated beginners by the same methods that were used so successfully in advanced study. But altho the method as practised proved successful, it had to be abandoned in 1829 because it was too expensive for the slender resources of the school. As the number of students increased, still more didactic methods were introduced; until in 1850, when the French curriculum was adopted (page 12), the student lectures had become blackboard demonstrations prepared from texts followed by "interrogations" and recitations conducted by the professors.

At the opening of the Massachusetts Institute in 1865 instruction was given mainly by lectures, in which the professor presented to the class a logically well-organized explanation of the general principles and theories of the subject in hand. Lectures were illustrated by experiments and accompanied by blackboard demonstrations. The students took notes, recited on them at regular quiz hours, and worked problems that illustrated the principles and theories presented. Frequent and thorough examinations were given for the double purpose of testing knowledge and inciting to diligence. As soon as the facilities were available, laboratory work was introduced, in which the student reproduced standard reactions, measured known constants, verified theories, visualized principles, and acquired skill in manipulating delicate instruments.

The use of the illustrated lecture in instruction in science was not new, but the organization of laboratories for undergraduate students in physics was a striking innovation, suggested by President Rogers and carried out by Professor E. C. Pickering in 1869. The course consisted of a series of simple experiments illustrating fundamental principles or scientific methods of study and involving the use of important instruments. The administration of the work was made practicable by having complete apparatus for each instrument ready for use together with carefully prepared written directions for its correct manipulation. When a class entered the laboratory each member received a number directing him to the apparatus and written directions for making the required measurements and recording the results. In this way Professor

Pickering was able to care for a class of twenty-five students at one time, because, as he himself tells us, the written directions prevented the students from making serious mistakes.

The marvelous expansion of this method of laboratory work into all branches of science in all grades of schools and the profound impress made by this expansion on the American school system are matters of common knowledge. Here it is important to note that this type of laboratory work was devised as an adjunct to the illustrated lecture, for the purpose of giving training in pure science, to foster industrial production, and develop the scientific or professional engineering spirit.

Besides the innovation of the laboratory, new methods of teaching English were introduced at the Massachusetts Institute by Professor W. P. Atkinson, who sought to cultivate a taste for good literature and a love of reading on subjects of interest to the student as a man and a citizen. After a rapid review of composition and rhetoric the classes read and discussed Duruy's *Histoire des temps modernes* and Guizot's *History of Civilization in Europe.* In the fourth year contemporary problems of politics, economics, and sociology were discussed and written reports on subjects of their own selection were read by the students in class. Two hours a week throughout the four years were devoted to this work.

Since 1864, but especially since 1900, the increase in the number of students and the migration of students among the schools have tended to standardize methods of teaching in both high school and college. In the secondary school the process has been accelerated by the pressure of college entrance requirements and the accompanying definitions of the units framed by the colleges, while in the colleges the process has been retarded by the universal respect for departmental autonomy and academic freedom with the consequent "laissez faire" attitude toward the problem. Under these conditions some college subjects have become more standardized than others, but it is seldom possible to point to any one method in any one subject as generally accepted. At present there is a marked tendency in certain subjects to break away from the traditional forms. Some of the efforts in this direction are noted in subsequent chapters.

While there are many differences in the details of curricula and methods of teaching, the first two years of work are more nearly uniform than the last two in content and general treatment. The freshmen in almost all schools take mathematics, chemistry, English, drawing, and shopwork; while sophomores usually study mathematics, physics, English, drawing, and shopwork. The methods of instruction in some of these fundamental subjects, like mathematics and physics, are very much the same everywhere; while in chemistry, English, drawing, and shopwork there are wider variations and several distinct types. Still the salient features and the underlying philosophy of the instruction in each subject are enough alike at most institutions to make possible a description of the typical treatment accorded to engineering students during their first two years in college. Certain striking exceptions in which totally different conceptions and methods prevail are discussed in the later chapters.

The aims and methods of teaching mathematics to engineering students have been fully described in the report of Sub-committee IX of the International Commission on the Teaching of Mathematics.[1] From this report it appears that mathematics teachers are generally agreed that mathematics should be taught as a science by professional mathematicians and not as a tool by engineers. While all regard professional efficiency in the use of mathematics as the test of success, they hold that this efficiency is best secured by teaching mathematics by itself, so that the student's mind is not distracted from the mathematical form by the engineering applications. The limited amount of time allotted to mathematics is barely sufficient to enable the mathematics teacher to cover the required ground thoroughly. If the teacher of engineering would familiarize himself with the mathematical subjects, the methods, and even the notation his students have learned, he could then teach them how to use their mathematics with a success and completeness not possible to his mathematical colleague.

Inasmuch as the professors of mathematics are generally agreed on this point of view, the mathematical instruction to freshmen and sophomores is almost universally based on the use of a standard text, in which the successive propositions are deduced by logical processes from definitions, axioms, and postulates. A definite portion of the text is assigned as a lesson, and in the daily recitations the students are required either to reproduce demonstrations given in the text or to solve mathematical problems that illustrate the theorems under discussion. The customary division of mathematics into trigonometry, analytics, and calculus is preserved at all but two of the schools visited. In short, mathematics in engineering colleges, as in the high schools, is still taught by the standard methods that are so well known as to need no further description. According to the report just mentioned (page 30), "There is nothing to indicate that many changes have taken place during the past 10 years, or that many are contemplated."

In chemistry the basis of the instruction is the demonstration lectures, at which the entire class assembles two or three times a week. For the quiz and laboratory work the class is divided into sections, usually in charge of assistants. A standard text is generally followed by the lecturer and used by the students as a source of information for the quizzes. A separate manual containing directions for the laboratory experiments is customary.

In most of the schools visited the presentation of the subject-matter in chemistry begins with general statements about atoms, molecules, chemical equations, Avogadro's law, molecular weight, chemical affinity, diffusion, valence, and formulas. Then follows descriptions of the non-metals, oxygen, nitrogen, carbon, etc., — their occurrence, preparation, and properties, — leading to the metals in due order. The facts discussed in the lectures are learned for the quizzes and verified in the laboratory. The purpose of this type of instruction is to familiarize the student with the elementary

[1] United States Bureau of Education, Bulletin No. 9, 1911.

facts and reactions of chemistry as a means of identifying substances and therefore as a preparation for qualitative and quantitative analysis.

Recently another type of course in chemistry has been introduced in a number of schools. In this the data are presented not as elements prerequisite to a mastery of chemical analysis, but as vehicles for the elucidation of modern chemical theories. In courses of this type the study of oxygen includes such topics as the diffusion and liquefaction of gases, critical temperature, endothermal and exothermal reactions, the gas laws, and the kinetic-molecular theory of matter. Similarly the facts about hydrogen are used to elucidate reversible reactions, chemical equilibrium, equivalent and atomic weights, and chemical equations. The study of water furnishes a natural thread on which to string the law of combining volumes, Avogadro's theory, molecular weight, solutions, and the kinetic theory of solution. The properties of chlorine serve as a basis for the presentation of electrical conductivity of solutions, osmotic pressure, ionic theory, degrees of ionization, electric charges on the ions, valence of the ions, and the electron theory. About ten weeks is required to cover these topics, and then the remainder of the year is spent in studying the more important reactions from the standpoint of the ionic theory. Incidental references are made to the industrial uses of chemistry.

Altho these two types of courses in chemistry differ in content, both use the lecture-quiz-laboratory method of imparting information. In one case the information is being stored for later use in chemical analysis; in the other it is being organized for the elucidation of ionic theories. In neither case is the student given such a project as: "Make baking powder and determine whether it is better and cheaper than any you can buy." His problem is always in the form: "Determine the chemical composition of this powder."

Physics is generally taught in the second year as a one-year course, tho five of the schools visited devote some time to it in the first year. As in chemistry so here, the typical course consists of three parts, demonstration lectures, quizzes, and laboratory work. In the lectures, of which there are two or three a week, the professor presents the essential facts and principles in a logically well-arranged order, beginning with definitions and statements of laws, followed by their mathematical or experimental demonstration, and ending with a few brief remarks concerning practical applications. Usually the entire sophomore class attends the lectures in a body; so that, in the larger schools, there are as many as three or four hundred students at each lecture. For quizzes the class is divided into sections of from twenty to twenty-five each; and these are turned over to assistants who listen to recitations on assignments in the text, question the students on the content of the previous lecture, and assign illustrative problems to be solved at home. With large classes of from twelve to twenty sections the quiz and laboratory work requires a large corps of assistants, many of whom are graduate students or fellows who receive a modest stipend (from $200 to $500 a year) for this service.

In the laboratory work the methods and aims defined by Professor Pickering in

1869 are still dominant everywhere. About one-third of his original experiments are still in use, and the new ones that have been introduced have as their objects the verification of some known law, the visualization of some known fact, or the determination of some known constant. When the same experiments are used year after year, as is the case at most schools, the students soon discover that the number of failures and low grades in physics can be materially reduced if the results of the physics experiments are carefully preserved from year to year and judiciously used as occasion may require. Projects of the form "Which of these 3 electric motors is the best for the price?"—a question that cannot be answered without making the experiment—are almost never used. The prevailing type is "Measure the efficiency of this electric motor." In other words, physics instruction, like that in chemistry, aims to stock the student's mind with information as a preparation for solving real problems should they ever arise.

The proficiency and the progress of students in mathematics, chemistry, and physics is measured by periodic examinations, which as a rule call for the statement of definitions, the mathematical demonstration of principles or theorems, and the solution of illustrative problems. For small classes the professor himself is usually alone responsible for the questions, and is also sole judge of the rating of the replies. For large classes the examination is sometimes set by the professor in responsible charge and sometimes by the entire group of instructors in conference. In either case the papers are as a rule distributed among the instructors for rating so that the grade assigned is often determined by the judgment of a single observer. The final grades assigned for the year are a combination of the examination grades, the quiz grades, and the laboratory grades. In making the combination the weights given to these several elements vary enormously, some treating the examination as the sole factor and others relying mainly on the quiz and laboratory grades. The students are generally well posted on the system used in each department, and their grades are fairly accurate statements of their successes in meeting the requirements of the various professors.

With regard to instruction in English, the engineering schools may be divided into two approximately equal groups, the one composed of those schools that maintain the current standard college course; and the other composed of those that are trying to discover a type of work better suited to engineers. In the standard type of course, the student studies a textbook of composition and rhetoric, learns the rules of correct punctuation and paragraphing, together with the four forms of discourse, and then writes themes on assigned subjects selected by the instructor to give practice in either description, narration, exposition, or argumentation. In some schools the strict adherence to this plan is mitigated by allowing a choice from among several assigned subjects. The accompanying study of literature consists of a brief survey of the lives of the great writers and the analysis of selected passages from their writings. This well-known type of course was developed during the latter half of the past century for the purpose of making English an acceptable substitute for the classics in high schools and colleges.

Doubtless because the professional engineers have been so frank in their demand for better training in English, about half of the engineering schools are experimenting with their methods of teaching this subject. These experiments are so varied in plan and execution that it is not possible to classify them. One of the more radical of these is described in Chapter X.

But if it is impossible to describe the types of instruction in English because of their number and diversity, it is still more difficult to select any one type of drawing, descriptive geometry, or shopwork as characteristic of even a majority of the schools. In drawing the aims of the instruction range all the way from imparting enough technical skill to enable a graduate to earn his living as a draughtsman, to developing the power of visualizing solid objects from flat drawings. At some schools the subject is introduced with geometrical drawing for practice in the use of instruments, at others the first plates are merely copied, while at still others freehand sketching in perspective takes the lead. In some cases descriptive geometry is closely correlated with drawing from the beginning; in others it is treated independently and even by a separate department.

The variations in types of shopwork are no less numerous. At some few schools no shopwork whatever is required; at others students merely visit shops and listen to lectures on the subject, but do no actual work with tools; at still others the emphasis is placed on acquiring a certain amount of manual dexterity in typical operations with tools, but nothing is actually constructed; at others production of salable articles is placed foremost; the shop is used in some cases as a means of acquiring practice in scientific management and business administration; while under the coöperative plan the school conducts no shopwork, but the students gain practical experience with tools, production, and management by working half time for pay in industrial plants.

It is a striking fact that the three subjects in which there are such wide variations in teaching practice are the three that are constantly exposed to objective test. English, drawing, and shop are three subjects in which a student's ability is expressed objectively if at all; and these are the subjects in which experiments in methods of teaching are most numerous.

These six subjects — mathematics, chemistry, physics, English, drawing, and shop — occupy the major part of the time for the first two years in all engineering curricula. The majority of schools also require one or more foreign languages, taught almost invariably by the standardized method of grammatical study and analysis. The civil engineering curriculum usually includes in the first or second year the theory of surveying, followed by a summer camp for practical work. Apart from this work in surveying, there is as a rule very little that makes the freshmen or the sophomores vividly aware of the fact that they are studying engineering. This has been recognized as a defect by some schools, which have sought to remedy it by "orientation" lectures and talks by professional men describing the nature of real engineering work in the field. Still there are cases on record where freshmen in engineering have been "weeded out" entirely because of deficiencies in English and German.

The instruction during the last two years is almost wholly devoted to professional work. The prevailing methods of teaching are very similar to those used in the earlier years in chemistry and physics, the difference being that the topics and problems are technical rather than purely scientific. Since specialization has now divided the juniors and seniors into groups, the classes are generally small and they receive the attention of the older and more experienced professors. Theory and theoretical design are strongly emphasized throughout and some attention — frequently very little — is given to the practical problems of labor, organization, values, and costs.

Twenty-five years ago every senior was required to prepare a graduation thesis as an exercise in the application of all he had learned and a training in engineering methods of attacking real problems. At present only half of the schools require theses of all graduates; in one-tenth the thesis is elective, in one-tenth the better students only are allowed the privilege of preparing one, and in the remaining three-tenths no thesis is required. Formerly the thesis was frequently the only opportunity given the student to exercise his originality and express his initiative in constructive work. At present engineering projects are being used more and more as problems and exercises in the regular class work of the last two years. In a few cases real engineering problems are freely used with freshmen and sophomores. These tendencies to encourage a spirit of investigation among the younger students and to give even freshmen opportunities for creative work are becoming more marked each year. Several significant changes of this kind are discussed in the later chapters.

PART II

THE PROBLEMS OF ENGINEERING EDUCATION

Chapter VIII

ADMISSION

The Society for the Promotion of Engineering Education has always had a standing committee on Entrance Requirements. This committee has made periodic reports, which are published in the Proceedings of the Society. Yet the variations in the requirements for admission to engineering colleges are still very striking (cf. page 22), tho the content and methods of instruction in many of the accepted units have been partially standardized by the effective work of the College Entrance Examination Board and of numerous committees on the definition of the high school units.

From the point of view of their success in limiting admission to engineering schools to those who have some aptitude or ability for engineering, it is evident that when 60 out of every 100 admitted fail to continue thru the course, present systems of admission are not satisfactory. Even when due allowance is made for those who leave for financial reasons and for the praiseworthy desire of faculties to give every boy who has any claim to consideration a chance to prove his mettle, a fairly large number of students who ought not to try to become engineers are permitted to undertake a course of study for which they have little natural ability. Nor is this condition justified by the plea that an engineering training is good discipline for a journalist or a banker; because the spirit of the work is spoiled for true engineers by the presence of the temperamentally unfit, while these do not get the maximum benefit from work they cannot really do well. Present systems not satisfactory

Fifty years ago every college gave its own entrance examinations. But as the secondary schools grew stronger, the custom of accepting their certificates as satisfactory credentials for admission gradually expanded; with the result that for a number of years two ostensibly rival systems have existed side by side, and many a wordy debate over their relative merits has been held. In engineering schools the statistics of elimination (page 32) indicate that the success of present admission systems does not depend seriously on whether the colleges give their own entrance examinations or whether they accept certificates from the secondary schools.

Reasons for the similarity of results by the two methods of admission are not hard to find. For every high school teacher who has in his class one boy preparing to take a college entrance examination is fairly sure to drill the entire class on old college entrance examination questions, large collections of which have been reprinted by publishers of textbooks and individuals interested in maintaining the examination system. Under these conditions if both college and school are sincere in their work,—which unfortunately is not always the case,—it clearly makes little difference in the boy's real attainments at the end of the course whether he takes his examination at school or at college. In the one case he is admitted by examination, in the other by certificate; in either case on the average at least 60 out of 100 admitted fail to exam certificate } no difference

Not machinery of admin
Nature of test

finish the course. Evidently the source of the difficulty does not lie in the machinery of admission, but in the controlling factor that is common to both, namely, the nature of the test itself. For engineering the question, therefore, is not which of the two methods of admission is the more efficient, but whether current college entrance tests really measure engineering ability or not. Ability to secure high grades in school is a stable characteristic of an individual; but is ability to pass current school and college examinations a valid criterion of engineering ability? And if not, what type of test can be safely used? This is the real problem of admission as it is the real problem of the entire college course, for tests control teaching.

Trustworthy hints as to the ways and means of discovering better types of tests for admission to engineering colleges are expressed in the recent developments of entrance systems. For when every college gave its own entrance examinations in its own way the secondary schools were confronted with a perfectly impossible task. In each subject there were as many different examinations as there were colleges; and since each examination measured rather the degree to which the candidate conformed to the examiner's conception of the subject than the student's real ability, great confusion prevailed. It was to abolish this confusion that the College Entrance Examination Board was organized in 1900. By having the examination questions framed by committees instead of by individuals, by giving the same examination for a large number of colleges, and by having all the rating done by one group of readers, conditions were vastly improved, and have continued to improve as the board has gained in experience and skill.

In the central and western states, where admission has for a number of years been by certificate, the development has been nominally somewhat different. There the decision as to whether the work of a high school was of such quality as to warrant the acceptance of its certificate for entrance to college was made first by professors sent out by the colleges; then by state high school inspectors, who visited each school periodically and reported their findings to the state universities. On the basis of their reports a list of "accredited schools" was constructed for each state, and these lists were combined by such organizations as the North Central Association of Colleges and Secondary Schools to include the schools over a wide territory. Recently there has been a tendency to check the findings of the high school inspectors by the ratings received in college by the students from the various schools.

Entrance Tests
Individual-Group.

While the respective developments of admission systems east and west appear to be quite different, they are in reality very much the same. In the examination system committees instead of individuals both set the questions and grade the papers. In the certificate system the work of a high school is now judged more by the ratings of its students by a college faculty than by the personal judgment of one high school inspector. Hence in both cases the growth has been away from reliance on the personal judgment of individuals toward acceptance of the combined judgment of a group. Under the certificate system this combined judgment is based on daily observation of the student's labors for a number of months, while under the examination system the judgment in each subject is based on the reading of one paper.

From the foregoing facts it appears that the real difficulty with college admission systems has been instinctively recognized everywhere. The determination of a candidate's fitness to enter college depends ultimately on tests of some kind; and the tendency in selecting and applying tests has clearly been to eliminate the fallacies and vagaries of individual personal judgment, in order that grading may become more a measure of ability and less an expression of how far the student conforms to the established convictions of individuals. But tho very encouraging progress has been made of late, all recognize that still greater improvement is possible, and that the forward movement is in the direction of reducing the personal equation to a minimum by making examinations and tests as objective as possible. Objective Tests needed

The expenditure of an enormous amount of time and energy has been necessary to liberate college entrance tests from personal bias and to achieve even the degree of objectivity that has been attained. The precipitation of the instinctive feeling for the direction of progress into a well-defined statement of conscious aim has proceeded slowly. Now that the aim is clear and generally recognized, more rapid advance is possible, provided the schools are ready to undertake the arduous and plodding work involved; for both the invention and the interpretation of satisfactory tests require long and careful statistical studies by competent men who have been specially trained for the task. The work is worth while because admission to college is an important division of the central problem of education — vocational guidance. If any reasonably trustworthy method of discovering what work each individual is best fitted for can be found, the other problems of education will in large measure solve themselves.

Since engineering is perhaps the most objective of all professions, it offers excellent opportunities for the scientific study of objective tests. A study of engineering education therefore provides an appropriate opportunity to initiate experiments and to attempt to sort out the more promising methods of investigation from those that prove to be less fruitful. To this end Professor Edward L. Thorndike of Columbia University undertook a special series of experiments with freshmen in engineering at Columbia, Massachusetts Institute of Technology, the University of Cincinnati, and Wentworth Institute. The experiences with the Columbia group are here described as typical of the principles and methods applied. Further details with samples of the tests used are given in the Appendix (pages 117–125).

Thru the courtesy of Dean F. P. Keppel, an invitation was extended by Professor Thorndike to forty freshmen in engineering to spend two successive Saturdays (fourteen hours) in taking the tests. Each of the thirty-four students who completed the series was given a small fee and a full statement of his record. Fifteen tests in all were used, each designed to record the student's relative ability in some one particular activity which was complete in itself, altho it involved a rather complicated series of reactions. Thus each student was asked to read paragraphs and write answers to questions on their meaning, to identify words as proof of his range of vocabulary, to supply missing words in sentences, to solve arithmetical and algebraic problems, to perform algebraic computations, to draw graphs from given data, to give geometrical proofs of stated theorems, to solve problems in physics described in words, to arrange physical apparatus to secure stated results, to match each of a series of pictures with one of a series of verbal statements, to supply missing lines in drawings of machinery, and to construct simple mechanical devices from their unassembled parts.

Each test was constructed as a series of graded steps of increasing difficulty, the first being so easy that every one was sure to accomplish it, and the last one so difficult that only the ablest could master it. The grading of the steps is secured by first submitting a large number of problems of a given type to about a dozen successful teachers of the subject and asking them to divide them into groups numbered 1, 2, 3, 4, etc., in what they consider to be the order of difficulty. Problems common to group 1 are used as the first step, those common to group 2 as the second step, and so on, in making up a preliminary test, which is then tried on a number of classes in different schools. The relative difficulty is then in inverse order to the number who accomplish each step. Much further experimenting and computation are necessary if it is desired to make sure that each successive step is more difficult than its predecessor by the same amount. Most of the tests used in these experiments with engineering students were graded in steps of equal difficulty.

The advantage of tests of graded difficulty lies in the fact that a student's grade is determined by the number of steps he accomplishes in the assigned time. Since the questions used are as a rule of a type that cannot be answered from memory, but must be answered by a short statement, judgment concerning the correctness of the answers is seldom ambiguous, so that personal bias in assigning grades is almost wholly eliminated. Independent scorers in these tests repeatedly made ratings that were practically identical (correlations .95 to .98. Cf. page 119).

Ultimate test future careers.

The ultimate criterion of the validity of these tests is the future careers of those tested. Since extensive data of this kind are not yet obtainable, the results of the tests were compared with a composite rating compiled by combining the students' high school marks in English, mathematics, and physics, their ratings in the Regents' examinations in these three subjects, their freshman records in English, mathematics, and chemistry, the combined judgments of the students concerning one another's intellectual ability, the judgment of the teachers who were acquainted with the men, and the age of entrance to college. This composite is the best obtainable summary of the current school judgment concerning the relative intellectual abilities of the students tested. By it the thirty-four who took the tests were ranged in a series in the order of their relative standings as determined by current school methods.

The students were then arranged in 15 similar series, the order of merit in each being determined by the ratings in one of the 15 tests; and each of these 15 series was compared with the series defined by the schools' ratings by the method of Pearson correlation coefficients (Appendix, page 119). Every test showed a positive correlation with this composite school series, the correlation coefficients varying from .2 to .8.

This indicates that all the tests are symptomatic of the qualities which enable a student to enter college young, make a good record in high school and in the Regents' examinations, do well during the freshman year, and be regarded as of high general ability by his classmates and teachers. When all fifteen tests are combined into a single measure, the test series and the composite school series are almost identical (correlation coefficient .84).

The records of the thirty-four men tested at Columbia have been followed for three years. Five of the seven who stood highest in the tests received general honors, while five of the seven lowest in the tests failed in more than half of their work and left school. The top seven all made more than 125 credits in three years, the middle seven averaged 92 credits each in three years, and of the lowest seven the two who did not leave averaged 56 points each in three years.

The tests, however, differ in their validity as symptoms of intellectual ability and should therefore have different weights in making up a summary. The computation of the relative weights was carried out by Dr. Truman L. Kelley by the method of partial correlation coefficients. His investigation shows that a suitable combination of the ratings from only seven of the tests gives a closer correlation with the composite school series than does the composite of all fifteen (coefficient .87 as against .84). These seven tests are the five in mathematics and the two in supplying the missing words from sentences. These seven tests require five hours of the student's time, and their results arrange the students in an order of intellectual ability practically identical with that of the composite school series. At present the composite school judgment is universally accepted as determining fitness to enter college. College entrance examinations consume from fifteen to twenty-five hours of the student's time. These seven tests gave in this experiment at Columbia as good a rating in five hours, and the scoring is independent of personal bias. Similar results were obtained at the other schools.

To this rather striking fact must be added another no less important; namely, that the other eight tests contributed practically nothing to this result. These eight were paragraph reading, range of vocabulary, giving opposites of words, laboratory problems in physics, matching diagrams with sentences, completing imperfect diagrams, physics problems stated in words, and the construction of mechanical devices from their unassembled parts. The fact that these eight tests are unnecessary in determining an order of ability that closely resembles the order defined by current school practices does not mean that they are on that account useless. On the contrary, they are particularly valuable because they evidently measure abilities of which the current school methods take no account. Further experimentation is required to determine just what these other abilities are. They probably include language abilities that depend on interest in reading, clear grasp of the meaning of single words and phrases, power to keep in mind past context in reading a connected passage, skill in working with diagrams and apparatus, and mechanical sense. All of these are of prime importance in engineering. The development of all the men tested is being followed for the purpose of throwing more light on the questions here raised.

The same fifteen tests were given by Professor Thorndike thru the courtesy of Dean A. E. Burton to forty freshmen at the Massachusetts Institute of Technology, thru the courtesy of Dean Herman Schneider and with the cordial coöperation of Professor B. B. Breese to forty-one engineering freshmen at the University of Cincinnati, and thru the courtesy of Director A. L. Williston to sixty students at the Wentworth Institute in Boston. The students in these groups came from so many different schools that it was not possible to make a composite rating of their abilities on the basis of their school records. The college records of these men have been followed for two years, with the result that in Cincinnati the tests prophesied academic achievement in these two years as accurately as the college rating for one year prophesied the rating for the succeeding year (correlation coefficients .64 and .62). At the Massachusetts Institute the tests prophesied the college ratings for the two years four-fifths as well as the ratings for one year prophesied those for the succeeding year (correlation coefficients .49 and .64). The implication is that such tests as these tell as much about a student before he enters college as the college now knows of him at the end of his freshman year.

What objective test will tell.

The same tests were given to groups of students at four different institutions. A comparison shows large differences among the average abilities of the four groups. This indicates that certain schools, whether because of their locations, their reputations, their student activities, or the excellence of their training, attract boys of greater innate ability. When further developed and perfected, tests of this type may make it possible to construct a scale of freshman abilities, by which each school can measure the quality of each freshman class. It is conceivable that a similar scale to measure the abilities of the seniors may some day be constructed. Then the difference in the positions of the freshmen and the seniors on these scales would be a much more valid criterion of the success of the school work than any now available.

freshmen seniors.

Neither present admission systems nor objective tests take account of several important factors that in many cases have an important bearing on a student's efficiency in school work. For example, Professor Thorndike found that during their high school course two-thirds of the freshmen examined had spent more than 8 hours a week on work other than school work. The median number of hours per week of such work reported was 12 during school time and 40 during the summer vacation. Out of 72 freshmen at Columbia and the Massachusetts Institute, 21 reported no outside work, 37 reported from 1 to 9 hours of outside work, 11 from 10 to 19 hours, and 3 more than 20 hours. At Cincinnati all the engineering students spend half their time in outside work. One student, who was rated low in the composite school series but who made an excellent record in the tests, was found to be doing over 40 hours a week of outside work. It is clear that a record of the amount and the kinds of outside work done by students would be of value in determining fitness to enter college.

A record of boyish interests and activities might also help to reveal to college examiners the presence or absence of real engineering bent or temperament. The freshmen tested by Professor Thorndike were asked to indicate by numbers their present preference for bargaining, managing people, studying books, clerical work, mechanical work, farm work, work with animals. In the replies from 90 freshmen mechanical work was rated first or second 82 times out of a possible 200, which is three times as often as chance would give, and over three times as often as was the case for a group of school superintendents at the same age. Out of 103 engineering freshmen who reported on the matter of boyish activities, 91 had constructed on their own initiative mechanical or scientific devices such as cannons, telegraph lines, telephones, electric motors, arc lights, gasolene motors, lathes, steam engines, water wheels, boats, etc. None of the engineering schools at present record this type of information or make any systematic effort to use it or to interpret its meaning; nor do parents and elementary school teachers realize the importance of giving young boys and girls opportunities of expressing their innate mechanical sense in creative work.

Let no one imagine that the tests presented in the Appendix are a final solution of the college entrance problem. They are but the beginning of an effort to proceed one step farther in the direction indicated by the development of college entrance systems during the past twenty years. A large amount of experimentation and cross checking among different schools must be done to determine the validity of this type of test and to interpret the results of its use. Enough has been done to show that the principles of testing here presented are worthy of further investigation and that methods of procedure have been indicated that point to a safe road of real progress. As these principles are applied and these methods are developed by many observers in many schools, it may be possible to liberate college entrance from its present fetters and place it on a more rational and scientific basis.

The effect of such a development on the quality of preparation for college is sure to be most beneficial. College professors are at present the only teachers in the school system who are permitted to teach without one hour of special training for teaching. With mastery of their respective subjects and the highest idealism and sincerity, they devise specifications for the content of high school courses, and then enforce those specifications directly or indirectly by entrance examinations that do not really measure ability or create the best conditions for its development. When the colleges are able to define their admission requirements in terms of abilities as measured by objective tests, instead of in terms of subject-matter covered, it may be possible to lift the great incubus of ignorance that now oppresses the secondary schools, to supply the colleges with freshmen much better trained and sorted on the basis of ability, and to reduce the mortality of 60 per cent to a more reasonable figure.

Objective Tests
Subject matter

vocational guidance - objective tests -

Chapter IX

THE TIME SCHEDULE

When faculties were small and the number of subjects that seemed essential were relatively few, the problem of the time schedule was a fairly simple one. All the necessary courses could be arranged in a compact and consistent program that required the student to carry not more than 18 credit hours of work at one time and to study not more than four or five different subjects each term. But as science expanded and became more intricate, specialization was unavoidable. By 1890 the civil engineering student had to choose either general civil engineering, or railroad engineering, or topographical engineering. Similarly the prospective mechanical engineer had to decide by the end of his second year whether he would follow the general curriculum in mechanical engineering, or one that specialized in marine, in locomotive, or in mill engineering. Since 1890 this process of subdivision and specialization has advanced rapidly, pushing the student's choice of a specialty back into the first year, increasing the required number of credit hours in some cases to as many as 27, and at times loading his weekly schedule with from eight to thirteen different subjects.

If there is any one point on which practising engineers and teachers of engineering are in substantial agreement, it is that at present this specialization and subdivision of curricula has gone too far. The congestion that inevitably results is universally recognized to be a fruitful source of confusion to the student and a real cause of superficial work. Attention is distracted from mastery of the subject and encouraged to seek ways and means of securing passing grades with minimum effort; so that a rigid and exacting department is likely to get more than its share of time and labor. There is too little time for persistent thinking, too little opportunity to realize the joy of achievement, and too much inducement to join in the scramble for credits.

There are two obvious methods of relieving congestion, namely, more time or fewer subjects. A few years ago Harvard University and the University of Missouri expanded their engineering curricula to six years, partly to relieve congestion and partly to raise engineering to the rank of a graduate professional study like law and medicine. Both of these efforts have been abandoned, but Columbia has undertaken to continue the experiment. The University of Wisconsin for a number of years offered a five-year curriculum along with the regular four-year one, but this was given up because it proved to be a haven for "lame ducks" who could not accomplish the regular work in four years. Cornell still maintains a five-year curriculum and is much pleased with its operation. The five-year curriculum at Yale consists of two years of specialized graduate work added to the regular three-year curriculum that leads to the Ph.B. degree in engineering.

In the matter of fewer subjects a number of the best schools are succeeding in keeping the required number of credit hours below 18 per term, as at Cornell, Ohio State, Illinois, and Wisconsin. Under these conditions the tendency to congestion is relieved to a certain extent by having a fairly large number of specialized curricula and allowing some small choice of electives among the technical subjects in the last two years. Both of these devices really result in a reduction of the amount of subject-matter by a limitation of its range, and thus bring the schools face to face with the charge of training narrow specialists instead of broad gauge professional men.

Thus far neither more time nor fewer subjects have as a matter of fact cured congestion. For the amount to be learned in every field is so vast and is increasing so rapidly that whenever a professor gets more time for instruction, he usually tries to cover more ground; and this tendency is supported by many of the younger alumni, who keep suggesting the addition of this, that, or the other bit of information that was not given them in college, but would have been useful to them on their first jobs if it had been included in the curriculum. This pressure to keep up to date, combined with the natural reluctance of every teacher to abandon material he has once worked up for presentation to the class, is fairly certain to produce congestion even after it has been temporarily relieved. The real causes of congestion, however, with its well-known symptoms of mental confusion, superficiality, and scurry for credit, lie deeper. Their roots penetrate to the methods by which curricula are constructed and the educational conceptions on which they are based.

Engineering curricula were originally organized on a very different basis from those in other professional schools. The earliest instruction in law and medicine was given by the apprenticeship system. As these professions grew, it was found convenient to gather the apprentices together in groups for class instruction by some particularly well-qualified practitioner. These classes were then organized into schools controlled and managed by practitioners, who, until recently, also gave the greater part of the instruction on a part time basis. The first law and medical schools at universities were practitioners' schools appended to, but never fully assimilated by, the institutions to which they were attached. Full time college professors of medicine and law are of relatively recent date, and even now much of the instruction in these subjects is still given in university schools by practitioners on a part time basis. The curricula of these schools, therefore, developed out of apprentice courses and were framed by men in daily contact with professional work.

In engineering, on the other hand, altho the apprenticeship method of training was originally employed and is still in extensive use,—about half of the professional engineers in America to-day being shop-trained men (page 19),—this system of training never developed into engineering schools to any extent. The first engineering schools were founded by colleges, their professors were college-trained men, and their curricula were devised by college faculties; professors also gave practically all the instruction with very little assistance from practitioners. For this reason the first technical schools had a serious struggle to prove that engineers could be trained in schools. Even now technological schools are classed in the Reports of the United States Bureau of Education with universities and colleges; while schools of law, medicine, theology, dentistry, pharmacy, and veterinary medicine are classed together as professional schools.

This dominance of the college of liberal arts in engineering schools has undoubtedly been a powerful factor in the development of the engineering profession. The emphasis still placed in the curriculum on pure science, pure mathematics, and the humanities, in spite of numerous vigorous attacks on them, is evidence of the extent to which the ideals of the American college still dominate the technological schools. But tho this protection of the conception of culture within the engineering schools has tended to liberalize them and to prevent their becoming too materialistic, it has not been an unmixed blessing; for that conception has been slow to adapt itself to the changed conditions produced by engineering, and has tended to preserve several fundamental practices that are now regarded as the probable causes of congestion and of other serious difficulties in current curricula.

Prominent among these outgrown practices is the method of constructing and changing curricula. When the students' hardships have become so obvious that they can no longer be ignored, a committee is appointed to study the problem and suggest changes. This committee usually requests each department to submit a statement of its requirements and desires; and, while this is being prepared, compiles a table showing how much time is allotted by other schools to each of the subjects included in the curriculum. The departmental statements are also compiled so as to show how much time is needed to fulfil all their requests. Generally the number of topics each department considers essential is so large that the hours required to cover them all would be double or triple the number available. The various claims are then discussed in committee, reduced within reasonable limits by a process of cut and fit, and the result reported back to the faculty. In the faculty debate that follows, each department presses its claims for more hours, and numerous changes are suggested, debated, and ordered made or not made by a majority vote. When the matter is settled each department takes the time awarded to it and uses those hours in any way it likes. In short, distribution of time among the departments is usually regarded as the chief function of the faculty. Respect for departmental autonomy forbids any investigation or scrutiny of the aims, the methods, or the results of the work of any one department by the faculty or by any of its committees.

Under present conditions the members of the various departments in engineering schools are selected in the main because of their abilities as specialists in their respective fields. Since every competent specialist is always an enthusiast over his specialty, there is no limit to the number of hours he would like to fill or the amount of information he would like to impart to the students, especially when the work is conducted by the lecture method. Therefore congestion of the curriculum is inevitable so long as each department remains sole arbiter of the content of its courses, and there is no coördination among departments with respect to the amount and the nature of the subject-matter in courses, and no scrutiny of the results of each department's work by some agency outside the department. The problem of congestion is evidently not merely a question of the time schedule, but leads at once to such specific departmental questions as: What is the minimum mathematical equipment essential to every engineer, no matter what his special line may be? What fundamental principles of mechanics must be mastered by every engineer? In developing a mastery of these principles of mechanics, what coördination of work among the departments of mathematics, physics, mechanics, and engineering is most effective? Until such interdepartmental investigations and experiments are the rule everywhere, instead of the exception, congestion is likely to persist and grow more and more disastrous.

Investigations and experiments of this type are already under way at several schools. Thus at the Naval Academy an effort is being made in the postgraduate department to coördinate mathematics with engineering by scanning the subject-matter of both to eliminate non-essentials, so as to make the treatment of each topic as brief as is consistent with clear understanding; there is also an earnest effort to arrange the material in both departments so that the presentation of the practical by the engineer and of the theoretical by the mathematician come at about the same time and complement each other.[1] Similarly at Cincinnati, many of the problems used in the mathematics classes are actual industrial problems brought in by the students from their practical work in commercial shops; and the work in English is so organized that theme writing gives outlook to the technical courses and technical reports are also exercises in English composition.

Important as are experiments of this sort in indicating present tendencies, their benefits are limited to the schools where they are made, because their results are not tested by methods easily recognized as valid, and the conclusions derived from them are not expressed in terms intelligible and convincing to all. To be widely effective, experiments must be checked by tests that are as free as possible from the personal equation and the errors of subjective judgment on the part of the experimenter. Therefore, ultimately, the problem of congestion leads, like the problem of admission, to the need for more impersonal and generally intelligible methods of testing and measuring the growth of abilities. The invention and perfection by experiment of objective tests of ability seems to offer the most promising road to progress toward a type of instruction that places less emphasis on information and more on ability to use information intelligently—toward greater coöperation among departments and less of the specialized exclusiveness of departmental autonomy, and hence toward the relief and the ultimate cure of congestion. This question is discussed further in the following chapters.

The seriousness of the problem of congestion has been widely recognized. There is, however, another closely related and equally important problem the significance of which has not been so fully apprehended; namely, the order of sequence of the various

[1] R. E. Root: *Engineering Education*, vol. vii, pages 190–196, December, 1916.

courses. In this matter the 1849 curriculum at Rensselaer (page 12) imported a French style that has been followed implicitly ever since. The conception underlying this and all later curricula is that engineering is applied science; and therefore, to teach engineering, it is necessary first to teach science and then to apply it. In conformity with this conception the first two years of college work are almost universally devoted wholly to learning the fundamental principles of chemistry, physics, and mathematics. Only when the student has passed a satisfactory examination on these fundamental principles and their various non-technical applications is he permitted to work on engineering projects.

Some of the peculiar effects that result from this universal habit of teaching first the theory, then the practice, are now beginning to attract attention. Instructors who are close to freshmen and sophomores tell how bewildered and discouraged the under classmen often are because, having come to college to study, as they supposed, the dynamic agencies for doing the world's work, they find themselves merely continuing their elementary and high school drudgery with books and abstract symbols. Doubtless some of the freshman elimination is due to this discouragement, and it has been suggested that the drop in student grades in the sophomore year (page 33) may be attributed mainly to this cause. The question has also been raised whether failure to make good in these preliminary studies as taught, or to succeed in the tests as given, is really conclusive evidence of lack of engineering ability.

Several of the schools visited have found that the introduction of "orientation" courses and talks by practising engineers on the real experiences of the engineer's life are effective means of increasing the interest and strengthening the morale of the freshmen. A moving picture of an engineering enterprise in action is not without results. These realistic portrayals of the technique of practice lend reality to the book work and arouse the professional ambitions of the hearers. The actual participation in technical work under the coöperative plan at Cincinnati, Akron, and Lafayette, the summer vacation work in industrial plants, and the summer surveying camps all tend in the same direction.

Recently the conception that beginners might learn more quickly and thoroughly if real experiences were coördinated with their study of theory has been carried one step further by introducing real work into the class work itself. Perhaps the most striking of the several recent experiments of this kind is that conducted by Professor C. C. More of the University of Washington. Mechanics is generally placed in the third year so that the students may be well prepared for it in physics and calculus. The conventional course begins with the statement of definitions and the deduction of general principles, followed by the solution of typical problems. Professor More begins by asking the student to report on the safety of the sheet piling in a certain cofferdam whose dimensions and location are pictured and described. Theory and principles are worked out and proved as they are needed to solve the problem. Calculus and physics are freely used. This complete reversal of the conventional order proved so successful that last year the same course was tried, including the calculus, on one section of engineering freshmen, who mastered it with little more trouble than the juniors. As a result, the entire engineering faculty now sanctions this order of topics from application to theory as a great improvement over the older conventional one.[1] Other similar experiments are discussed in subsequent chapters.

Altho the engineering faculty at the University of Washington approve of Professor More's new order for teaching mechanics, other instructors in mechanics who cannot personally observe the results will be slow to follow or inaugurate similar experiments because there are no generally intelligible objective tests and scales of ability in terms of which the results may be expressed. For this reason experiments with the curriculum, either to relieve congestion or to secure more enthusiastic and intensive work thru variations in the nature and the order of the topics, have at best a limited effect. So this problem too settles down ultimately to one of inventing and defining tests and scales to measure variations in ability. Further uses for such scales are explained in Chapter XI.

[1] Cf. W. E. Duckering: *Engineering Education*, vol. iii, pp. 518–535, May, 1917.

Chapter X

CONTENT OF COURSES

One of the most striking and universally recognized features of the technological schools is their lack of agreement on the content of courses that bear the same or similar titles. Some of the more marked differences in elementary chemistry, English, drawing, and shopwork have been mentioned in Chapter VII (page 38). Obviously the 52 hours of calculus at Rensselaer cannot have the same content as the 216 hours of calculus at the University of Florida (page 24). Some of the courses in mechanics place great emphasis on the absolute system of units while others use only the engineers' units. In the treatment of descriptive geometry the number of essential problems varies from 27 to 86 and the number of fundamental conceptions from 6 to 12. The teachers of each subject not only do not agree on what equipment in their subject is essential for an engineer, but they have not yet taken the first step toward such an agreement, namely, the definition of the criteria that must govern the selection and the organization of the content of their several courses.

The prevailing wide diversity in the content of courses is clearly a necessary result of the general confusion as to ends, aims, methods, and rating of instruction. But while the many strong points in the present system are duly appreciated, it is gradually becoming evident that in training men for so definite a vocation as engineering, in which the various elements—science, mathematics, language, economics, and hand work—are so intimately interrelated, some agreement as to aims and some coöperation among departments in determining the content of courses is absolutely essential. That this need is recognized at all the schools is evidenced by the numerous common complaints among departments. The departments of engineering insist that the preliminary work in mathematics and physics is unsatisfactory because students who have passed these courses cannot use either mathematics or physics intelligently in the later technical work. Conversely the teachers of mathematics and physics claim that the students are poorly prepared in these subjects in high school and that the engineering departments make unreasonable demands. All the other departments decry the work in English and foreign languages as inefficient and wasteful of the students' time.

To remedy these well-recognized difficulties, conference committees are frequently organized and friendly meetings are held, in which each side explains its point of view. The resulting changes, however, are few. At one school a professor of mathematics voluntarily attended numerous classes in engineering subjects to get some notion of the mathematical needs of these courses. The course he devised on the basis of the information thus secured was so successful that he was called to a more responsible position in another institution; yet his colleagues did not carry on his experiment. At another school a professor of chemistry conducts a volunteer class in German in order that the students in chemistry may have a chance to get the practical mastery of German that every chemist needs. One professor of civil engineering and one of electrical engineering were found giving regular instruction to volunteers in English composition, both written and oral.

In spite of the fact that deviations from established practice in teaching are not encouraged, so that there is an almost universal disinclination to make changes, a few important experiments are being made for the purpose of discovering more appropriate content for courses. Prominent among these are two in mathematics, one at the Massachusetts Institute of Technology and one at the University of Wisconsin. In both the aim has been to construct a single two-year course in mathematics in place of the customary but somewhat unrelated courses in algebra, trigonometry, analytical geometry, and calculus. Both courses have been published in textbook form; the former in Woods and Bailey's *Course in Mathematics*[1] and the latter in Slichter's *Elementary Mathematical Analysis*[2] and March and Wolff's *Calculus*.[2] While the particular categories under which the various topics are arranged are very different in these two courses, the underlying conceptions are similar, in that both attempt to reorganize the content of the mathematics courses for the purpose of securing a more logically coherent presentation. Each is a consistent working out of a mathematician's conception of the mathematical equipment needed by every engineer. This emphasis on logical sequence has undoubtedly a fascination to certain types of mind—teachers of mathematics, for example. Its effectiveness with the great majority of students may well be questioned, especially when the logic is expressed in curves and symbols carefully detached from technical applications. Both of the courses just considered claim to pay particular attention to applications, but these are mostly of the non-technical variety. In the Woods and Bailey text, out of 2288 problems for drill in the application of mathematical principles, only 103 even mention material things; while in Slichter's book, only 146 out of 1102 problems discuss concrete realities.

The experiments just described are typical of one method of attacking the problem of finding more significant content for engineering courses. The emphasis in reorganization is placed on more logical and coherent sequence of topics and a better adaptation to modern scientific theories, with little attention to the introduction of engineering content into the mathematical forms treated. To some extent the content of courses in physics and chemistry is being reorganized into more logical and coherent presentations of current kinetic and ionic theories of matter. The methods of instruction followed in experiments of this type are usually much the same as those of the old standard courses.

A second type of reorganization of content is being worked out by Professor H. M. Goettsch at the University of Cincinnati. After sixteen weeks of preliminary training very similar to that ordinarily given in courses in elementary chemistry, the freshmen work in the laboratory from 8 a.m. to 4.30 p.m. for ten weeks solving problems

[1] Two volumes. Ginn & Co., 1907. [2] McGraw-Hill, 1914.

of industrial chemistry. Projects such as "Make baking powder and determine whether it is better and cheaper than any you can buy" are assigned without any instructions or references, and the student is required to work out his own salvation in the library and the laboratory. In the period of ten weeks he completes a number of these projects covering a wide range of topics, but little effort is made to present the topics in logical or any other sort of orderly sequence. Much emphasis is placed on synthetic work and on the cost of a given product by different processes; while chemical analysis and the ionic theories of matter, which usually occupy the centre of the stage in chemistry courses, here take a subordinate place. The course in mechanics devised by Professor C. C. More at the University of Washington (page 58) is another example of this type of reorganization of content in which the logical sequence of topics is subordinated to project work, and theory is evolved from rather than illustrated by problems and experiments. Professor R. M. Bird conducts his course in elementary chemistry at the University of Virginia on this plan with great success.

The content of courses of this type is clearly determined by considerations both of logical completeness and of pedagogical vigor. For a series of interesting projects that does not eventually compel the student to work out a fairly complete conception of the large theories and the important principles of chemistry is obviously inadequate, no matter how enthusiastic the students are in their work. On the other hand, altho the suggestion that an effective course can be constructed as a series of apparently disconnected projects comes as a shock to those who have grown up with logically rigorous courses, the value of the enthusiasm engendered by well-chosen projects must not be overlooked. Our most valuable information and training come from working out projects that are really worth while; and if this method works in life, why not in school? Especially since in educational institutions it is always possible to organize significant projects into a connected series that leaves a well-developed conception of the whole subject in the student's mind. This has been accomplished in the courses just mentioned, where the summing up is done after sufficient facts to warrant summaries have been secured. Their success should encourage others to further experiments. The inclusion of considerations of values and costs in the content of these courses is also an element of enrichment that deserves careful attention.

Those who find a series of projects an unsatisfactory course of instruction, but who nevertheless wish to make the content real and of great value to the students may find many worthy suggestions in Professor R. H. Fernald's course in power plants at the University of Pennsylvania. While the topics in this course follow one another in a logical sequence, they are chosen largely from engineering practice, and include much of the practical information every engineer must have when he goes to work. Many of the problems are actual cases that really occur in engineering, so that they appeal both to professional instincts and to the sense of values and costs—in fact, many of them are openly problems that deal with costs of operation and maintenance in working plants. Yet the course is not a mere mass of useful information; rather useful information is the vehicle for conveying to the student a firm grasp of fundamental principles and engineering methods of attacking and analyzing problems not only from the point of view of scientific theory but also with due consideration of the limitations imposed by practice and by costs. Professor Fernald's course has been published in textbook form,[1] and a number of other schools have adopted it and are following it with satisfaction.

The emphasis given in this course to the economic aspects of power plant problems is an encouraging sign of the dawning recognition of the profound importance of this side of engineering in technological schools. Most of the technical colleges now include short courses in economic theory, banking, contracts and specifications, etc.; a few give some small amount of practice in figuring costs and making bills of materials from drawings assigned by the instructors. Here and there the attention of the students is directed to the practical difficulties of construction and the controlling power of costs. There has always been and still is a strong aversion on the part of colleges to placing emphasis on the material and financial aspects of the engineer's work. Yet it is a burning question whether the commercial bearings of each subject cannot be introduced into every course in such a way as to increase enormously its use and its vitality without in the least impairing its inherent scientific value. The enrichment of the content of courses by judicious appeal to practice and costs is a problem that offers rich opportunities for further experiment.

But if experiments of this sort are undertaken in large numbers in every school, there is obviously serious danger of actually becoming too materialistic, thereby sacrificing powers of abstract thought and humanistic ideals on which real progress ultimately depends. Efficiency in the mastery of materials without humane intelligence to guide and control it is now recognized in all civilized countries as a curse. Hence great care must be exercised in making these experiments, and every effort must be made to enforce the truth that mechanical efficiency, while essential to success, is servant and not master. The opportunity offered to the humanistic studies by this situation has already been perceived at a number of schools, and many efforts are being made to alter the content of the courses in English, in history, and in economics to meet the obvious need. Perhaps the most striking experiment with this aim is that now being made by Professor Frank Aydelotte in coöperation with the members of the department of English of the Massachusetts Institute of Technology. At this school English is a required subject for all students throughout the first two years. The first half of the freshman year is devoted to general composition, with the object of eliminating the more common errors of construction and of leading the student to see that excellence in writing comes not so much from the negative virtue of avoiding errors as from the positive virtue of having something to say.

The work of the second term of the freshman year begins with a class discussion of such questions as: What is the difference between a trade and a profession? What

[1] R. H. Fernald and G. A. Orrok: *Engineering of Power Plants*, McGraw-Hill, 1916

is the meaning of the professional spirit? What should be the position of the engineer in society in this new era of the manufacture of power—that of hired expert or that of leader and adviser? Is the function of the engineer to direct only the material forces of nature, or also human forces? Such questions readily arouse the interest of engineering students and bring on thoughtful discussion, in which different points of view are expressed by the students and debated with spirit. Essays by engineers are then assigned for reading, and after further discussion each student is asked to write out a statement of his own position on the mooted questions. These themes are criticized in personal conferences in which faults are corrected by asking the writer first what he intended to say; and, second, whether the sentence or phrase in question really says it, rather than by reference to formal rules of grammar and rhetoric. Those who have had experience with this work claim that once the habit of self-criticism from the point of view of the idea is established, the student makes astonishing progress in the ability to express himself clearly and independently; he gathers hints from all sources; and in ways too complex for pedagogical analysis he is more likely to acquire such power over language as he is naturally fitted to possess, than he is by current formal methods. For the achievement of this complex end, the conventional instruction in technique is too crude and clumsy to be of more than incidental use.

Having discussed the question: What is engineering? the class proceeds in the same manner to wrestle with such problems as: What is the aim of engineering education? What is the relation between power of memory and power of thought? Is there any connection between a liberal point of view and capacity for leadership? What qualities do practical engineers value most highly in technical graduates? What is the relation between pure science and applied? What is the relation of science to literature? The authors read in connection with the discussion gradually change from engineers to scientists like Huxley and Tyndall, and then to literary men like Arnold, Newman, Carlyle, and Ruskin. The student seems to read this material with no less keen interest than was shown for the writings of engineers; so that thru his own written and oral discussion of masterly essays each comes to work out for himself some rational connection between engineering, with which he began, and literature, with which he ends. No orthodox point of view is prescribed; his own reason is the final authority. The aim is to raise questions which it may take half a lifetime to answer, but the thoughtful consideration of which will give a saner outlook on life and on his profession.

A similar experiment along analogous lines is being made by Professor Karl Young and his colleagues in the department of English at the University of Wisconsin. Reports indicate that this type of course is a great success there also. The materials used in both these courses have been reprinted in book form for the convenience of the classes.[1]

[1] Aydelotte: *English and Engineering*. New York: McGraw-Hill, 1917; *The Oxford Stamp*, Essay X. New York: Oxford Press, 1917; Foerster, Manchester & Young: *Essays for College Men*. New York: Holt, 1913.

The four typical experiments just described indicate that the reorganization of the content of courses is being attempted with a wide variety of aims, such as more logical coherence, better pedagogical organization, greater emphasis on the economic phases of the work, or a broader and more humanistic outlook. Many other aims are conceivable, and many combinations of these four are possible, so that there is unlimited opportunity for the further experiments that are needed as a basis for the reconstruction of the curriculum. The current method of framing curricula by first distributing the student's time among the various subjects by faculty action and then allowing each department to fill in its quota as it sees fit leads to the impossible conditions discussed in the preceding chapter. The way out lies in the direction of reversing the process; that is, first determining by coöperative faculty investigation what equipment in each subject is essential to every engineer, and then requiring each department to discover by experiment how much time is necessary to give adequate control of that essential equipment to the promising students.

In order to carry out this suggestion, entrance requirements must first be placed on some such basis as that described in Chapter VIII, so that the technical school can be reasonably sure that the majority of the students admitted show promise of success in engineering. Then for each of the fundamental subjects common to all engineering curricula an answer must be found by coöperation among all departments to the question:

What is the minimum equipment essential to every engineer, no matter what specialty he may eventually choose? The answers to this question must be stated in terms of ability to accomplish rather than in the customary terms of topics to recite; for example, the familiar "algebra through quadratics" must read "ability to make algebraic computations as difficult as required in solving for x in

$$\frac{x+a}{x-a} - \frac{x-a}{x+a} - \frac{x^2}{a^2-x^2} = 1\text{"}$$

After such statements of the minimum essentials have been secured, the respective departments will be able to construct their courses intelligently and to devise objective means of testing their progress.

There are at present two serious obstacles to carrying out the plan here proposed. One is the reverence for departmental autonomy, which makes all departments reticent about making suggestions to one another and inclines each department to regard any suggestion from another as unwarranted tampering with vested rights rather than as an intelligent effort to benefit the students. The other is the lack of generally intelligible and transferable scales and methods of testing. These two obstacles deprive such experiments as are being made of the greater part of their potential usefulness,— the former by limiting the scope of the experiment by the bias inevitable to every specialist, and the latter by making it impossible for the experimenter to state his conclusions in terms that are convincing to others. The chances for real progress in vitalizing the content of courses are increased in proportion as departments coöperate in defining the minimum essentials and as scales of ability and methods of testing are liberated from the errors of individual judgment. It is here that the teacher has his greatest opportunity for creative work; for when the content of a course is well chosen and the subject-matter is effectively organized to meet both the scientific and the human requirements, the game is worth the candle for the student and he plays it with energy and zest.

CHAPTER XI

TESTING AND GRADING

ABOUT half of the schools visited grade students on a numerical scale of 0 to 100, with pass marks varying from 50 to 70. Two grade on a scale from 0 to 4, one having 3 and the other 2 for the passing mark. The remaining schools ostensibly grade on literal scales (with per cent values attached); but of these, three have three grades above pass, designated respectively by A, B, C, or M, P, C, or C, P, L; and two have four grades above pass, indicated in the one case by A, B, C, D, and in the other by D, G, P, N. As a result, whenever a student transfers his credit from one school to another, it is very difficult to evaluate his record and determine his status in the institution to which he comes. Tho all student grades are apparently reducible to numerical values, a grade of 88 is hard to interpret even when you know the school and the instructor that gave it, because each school and each instructor has a personal equation in grading.

After one year's experience with a group of students, a teacher of mathematics, for example, undoubtedly possesses more information concerning the mathematical interests and abilities of these students than can possibly be ascertained by a few hours of examination or testing. But his knowledge is largely in the form of personal experience and intuitions based thereon, which cannot be expressed in the usual record blanks and so is seldom transferred to other departments. The knowledge now possessed by the teachers in a school of engineering, tho abundant, is not accessible thru records; but is segregated in departments and individuals, and confused by personal equations. Even tho ability to secure high grades in school and college seems to be a stable characteristic of an individual (page 36), employers have long since learned that college records are precarious guides in selecting men for jobs.

About ten years ago Professor Max Meyer of the University of Missouri started a campaign to eliminate the personal idiosyncrasies of individual instructors from academic ratings by requiring every professor to distribute his grades over his classes approximately according to the probability curve. It was pointed out that when all the students at a university are arranged in the order of their average grades, about fifty per cent are found grouped about the middle grade, with about 25 per cent higher and 25 per cent lower. Hence the University of Missouri defines its grading system thus: "In classes sufficiently large to exclude accidental variations, approximately 50 per cent shall receive the grade M (medium); to the great majority of the 25 per cent above M the grade S (superior) shall be given; and to the few most excellent students the grade E shall be assigned; the majority of the 25 per cent below M shall receive the grade I (inferior), and the minority shall be given the grade F (failure)."[1] In order to render the grading significant to the students, 30 per cent

[1] Hyde: *Proceedings of the Society for the Promotion of Engineering Education*, vol. xxi, p. 175, 1913.

excess credit is granted for all work done with a grade of E, 15 per cent excess for work of grade S, and a 20 per cent reduction of credit is made for work of grade I.

The results of this experiment at Missouri and of similar investigations at other schools indicate that considerable progress is being made toward reducing the number of professors who either mark most of their students A or else fail a large percentage of them. The mere presentation without comment to each member of the faculty of his own grade distribution curve superposed on the average curve for the whole institution has been found to reduce abnormalities in grading without discussion or faculty action. Clearly this work is developing in the same direction as are the entrance requirements (page 49); namely, toward a reduction of the errors in grading that result from personal equations. There is need and opportunity for further effort to stabilize the distribution of grades along the lines of this experiment.

The study of the distribution of grades is now expanding in the direction of searching for the reasons for strikingly anomalous curves. In the schools visited a number of cases were found in which from 50 to 75 per cent of the students who graduated had received grades just slightly higher than the pass mark (page 34). Experience shows that when so large a fraction of a class receive such low grades there is some serious difficulty, which can usually be removed by investigation (page 35). As a result of numerous such studies it appears that the grading systems in current use possess several inherent characteristics which have been accepted so long as a matter of course that their normal effect on the distribution of grades seems to have been largely overlooked. Prominent among such characteristics are the convention of granting the same amount of academic credit for all grades of work above the pass mark, and the habit of leaving the definition of the basis of testing and grading in each subject wholly in control of the instructors who do the teaching.

The harmful influence of both of these characteristics of current marking systems is very generally recognized. Every college teacher knows well that many of the ablest students regard it as an evidence of poor management on their part if they get grades very much above the pass mark. College authorities have sought to break up this student tradition by offering academic honors of one sort or another, like Phi Beta Kappa, Tau Beta Pi, Sigma Xi, or honorable mention on the commencement program. A further and more effective step has been taken by the University of Missouri in granting excess credit for high grades, as just described. Other schools are trying the experiment of adding to the regular grading a system of honor points, so framed as to prevent the student from graduating on mere pass grades. But even these devices do not render the grades intelligible to employers and to other colleges, nor do they always inspire the student to maximum effort. The West Point grading system (page 28), on the other hand, does act as a real incentive to good work and as a genuine support for the maintenance of the honor system.

The reasons why grades under present conditions do not act as real incentives to good work are very similar to the reasons why payment of wages to workers on the basis of time spent at work fails to result in maximum output and even tends to scale down the efficiency of the skilful to that of the slothful. So long as the credit in both cases is determined mainly by the time consumed, the only accomplishment demanded being a certain minimum below which the job cannot be held, so long there is no real incentive to speed up and show mettle. Hence workmen "soldier" and even deliberately unite to deceive their employer as to how much work an able and ambitious worker can do in a day; and students have been known to practise analogous tricks on professors. All of which has a decided tendency to concentrate grades in a small area on the safe side of the pass mark. The device of granting bonus credit for high grades, while it improves the situation, is not likely to effect a real cure until grades are a truer measure of achievement than is at present the case. For the students know as well as anybody that college grades are very ineffective measures of the type of ability that wins recognition in the world's work—they know of too many notable examples that fortify their own personal observations and convictions in the matter.

The real cure for "soldiering" in college work has already been found and put into practice in one department, namely athletics. There the students submit gladly to rigorous discipline and exert themselves to the utmost in the games because the work appeals to them as thoroughly worth while and the score is a valid and objective measure of achievement. In their studies, on the other hand, the game does not always seem worth the candle, and their scores often depend as much on their ability to conform to the personal points of view of their instructors as on their real achievement in mastering materials. For under present conditions each department—frequently each individual instructor—sets all examinations and tests and determines the relative merits of the students by means of individual, subjective standards. College boys understand this perfectly, for it is not unusual to find bright ones among them who win high grades by studying the instructor rather than the subject. Obviously here, as in the case of admission, the need is for more objective methods of measuring student progress and more assurance that the tests used are tests of the abilities the engineer needs to have developed, rather than of something else the exact nature of which is at best vague, uncertain, and undefined.

The analysis of a large number of the examination papers and quiz questions in current use reveals the chief reasons for the vagueness and uncertainty of the results secured by conventional methods of testing. A large proportion of the questions can be answered by reciting or writing memorized words, phrases, or equations. How can the instructor decide whether correct answers to these questions mean merely a retentive memory, or whether they indicate clear understanding of the relations involved, or an ability to use them in practice? Again, many of the questions call for verbal descriptions of apparatus or processes. The answers to questions of this sort are frequently so ambiguous that it is impossible for the teacher to tell whether the students do not understand the subject, or whether they are unable to express themselves. Hence different instructors make estimates that may vary from 30 to 80 on the same paper; and there are no means of deciding as to which estimate is best. Finally, little effort is made to arrange the questions in their order of difficulty, by placing the easiest first and the most difficult last. Occasionally some questions are given greater weight than others, but the assignment of weights is apt to be an act of arbitrary judgment on the part of the instructor.

Since tests control teaching, it is obvious that one of the most effective methods of attacking the teaching problem is thru the study of tests. For the purpose of making a beginning of such a study aimed at removing some of the ambiguities of current examination practice, Professor E. L. Thorndike of Columbia University devised for seniors in electrical engineering a series of objective tests, analogous to those used in his experiments with freshmen (page 49). In planning the tests, and selecting the types of activity that seemed most likely to reveal abilities essential to engineering, Professor Thorndike was assisted by a volunteer committee consisting of Messrs. E. B. Katte, Chief Electrical Engineer of the Grand Central Terminal, New York; L. D. Norsworthy, Professor of Civil Engineering at Columbia University; F. P. Keppel, Dean of Columbia College; J. W. Roe, Professor of Mechanical Engineering at Sheffield Scientific School at Yale; the secretary of the Carnegie Foundation; and the author of the present study. Descriptions of the tests used in this experiment are given in the Appendix (pages 117, 118).

While some of these tests appear at first sight very similar to ordinary examinations, they are, as a matter of fact, constructed on very different principles. In the first place each test is intended to measure a specific ability, such as arithmetical computation, geometric construction, paragraph reading, understanding of words, mechanical dexterity, or comprehension of diagrams. Each of these is a single activity, altho requiring a complicated coördination of psychological processes. Then the tasks are so selected that their accomplishment can be indicated with little or no use of words, so that ability to perform the task is not confused with powers of verbal expression; and the errors of personal judgment in deciding whether an answer is right or wrong are reduced to a minimum. Because of this independence of the personal equation, results obtained by these tests at different schools, or at the same school at different times, are comparable with one another. Moreover, tests of this kind are capable of indefinite extension by alternative tests that give commensurable results. In this way the danger of cramming for any one set test may be avoided; since after the successful type has been found, it is a relatively simple matter to construct ten or twenty alternate tests on the same pattern. Again, the successive tasks on each test are arranged in the order of difficulty, beginning with one that can be correctly met by almost all students of the degree of training in question, and progressing gradually to one that can be done by only a very few of the most gifted. Such a test is a scale up which the student climbs to the extent of his ability in the particular type of activity under scrutiny; so that, when the test is well constructed, his relative rank is determined without ambiguity by the difficulty of the task he can successfully master, rather than by an estimate of how much credit must be given for a partially completed task.

Thru the courtesy of Mr. C. R. Dooley of the Westinghouse Electric and Manufacturing Company at Pittsburgh, these tests were tried out on a group of forty engineering graduates employed by that company as graduate apprentices. These apprentices are given very varied tasks, are observed by superior officers with a view to permanent employment, and are given ratings on a series of essential characteristics by every foreman under whose direction they work. The essential characteristics used in these ratings are: physique, personality, knowledge, common sense, reliability, open-mindedness, tact, initiative, attitude, originality, industry, enthusiasm, thoroughness, system, analysis, decision, English, and ability. In addition to these ratings by foremen, the two officers of the educational department of the company who are in closest touch with the work of the apprentices rank them after they have been there about nine months, for general ability and for order of choice for employment by the company. The apprentices themselves were also asked to rate one another, as far as acquaintance permitted, for promise of success in engineering.

The ratings thus obtained from the records by foremen, the estimates by the educational experts, the opinions of the apprentices themselves, and the tests were compared in many different ways. Unfortunately the college records of the apprentices could not be used, because so many different colleges with incommensurable grading systems were represented in the group. As a result of the analysis it appeared that the foremen's ratings would give as good a record if they used the six qualities—ability, analysis, originality, thoroughness, enthusiasm, and common sense—instead of the eighteen just mentioned. The order determined by the ratings by half the foremen agreed fairly well with the order determined by the ratings of the other half (correlation coefficient .48); and the order of merit in the judgment of one expert agreed fairly well with the order according to the judgment of the other (correlation coefficient .53); but the foremen's order and the expert's order did not agree so well (correlation coefficient .24). The correlation of the order given by the tests with the foremen's order was also .24 and with the expert's order .37.

The orders of merit given by the four different ratings were finally combined into a single order, which most probably represented the best order as determined by all available information. The individual orders were found to correlate about equally well with this composite (correlations are: foremen's records .73, tests .71, apprentices .70, experts .60). Hence in this case the tests, which require eight hours' time, appear to give as reliable an order of merit as do the judgments of either the experts, the foremen, or the apprentices themselves after six months of experience with the men in a specially well-organized industrial company. This does not mean that these tests are infallible, for even a perfect measure of achievement under one set of conditions would probably be in error, just as the judgment of experts would be in error, as a prophecy of later years of work under different conditions. The subsequent careers of those tested must be followed for a number of years and many other similar experiments must be made before the validity of any set of tests can be definitely established. It does mean, however, that, in a given case, a systematic test of eight hours may detect engineering ability and prophesy engineering success as effectively as expert personal inspection of actual work over a period of several months. It is this possibility that makes experimentation with this type of test so well worth while. The tests herewith presented are in no sense final. They are first approximations, requiring much study and trial for their perfection. Those who have studied these experiments closely are convinced, however, that the method of attack here used is sound, and that progress in the direction here indicated is both safe and sure.

Many experiments with objective tests of the type here described have been made in recent years in elementary and secondary schools. Similar tests are being tried on a very extensive scale on the members of the new national army by Major Yerkes, the well-known psychologist, who has accepted a commission in the army for this purpose. Industries, too, are beginning to look to these tests to guide them in the selection and placing of workmen, in the hope of reducing the labor turnover that is costing the country several hundred million dollars a year. Altho the movement is still in its infancy, enough has been done to forecast what may be accomplished by further scientific work in this field. In engineering, for example, it is conceivable that before long admission to college and achievement in college may be liberated from the bondage of personal equations as grading becomes less a matter of individual bias and more a valid record of actual accomplishment. Then college grades may be transferable among colleges; then academic marks may become significant to employers; then the results of educational experiments may be stated in convincing terms; and then students may come to respect their records and strive to beat them without artificial stimuli in the way of academic honors and credit bonuses.

The greater the number of schools that undertake experiments with tests, the more rapid the progress toward the attainment of these ends. It is not a question of merely superposing a few tests of the type described on the present examination and grading system. Such superposition may well be a first step; but ultimately it is a question of working the whole testing and marking system to a more objective basis, and this is a long and laborious task. For the final rating must include and express the enormous amount of information which teachers now gather about students by inspection of their work and by the regular examinations, quizzes, and reports, in terms that are intelligible for scientific and practical use. Then a rating becomes a safe instrument for vocational guidance, which is, after all, the fundamental problem of the schools.

When grading is conceived as an instrument of vocational guidance, rather than as an expression of the degree to which an individual has succeeded in conforming to an established order of things, more information is needed than can be secured from present tests and examinations. It is a striking fact that while most schools grade merely on academic work, most industries rate men on personal traits like character, initiative, tact, accuracy, responsibility, and common sense. This fact has led a number of schools to supplement their regular grades with estimates of personal qualities such as these. At Purdue, the University of Kentucky, Pennsylvania State College, and other engineering schools, elaborate records of personal impressions of students are kept on file and used with effect in guiding students into suitable positions. Usually the record card has the names of a number of the desired qualities printed on it, and the instructor is asked to place a grade mark opposite each. Sometimes each instructor does this in private, sometimes the grades are assigned after discussion in departmental meetings. In either case considerable difficulty is experienced in selecting the qualities to be graded and in deciding on the proper grade to be given to each individual for each of the qualities selected. Among the many schemes that have been devised for this purpose two seem to be particularly suggestive to schools of engineering.

The first of these schemes was devised by Professor W. D. Scott of the Carnegie Institute of Technology for the use of large business organizations in selecting employees and executives, and is now being used by the War Department at Washington for grading army officers. The qualities selected for grading in this case are: 1. Physique, including bearing, neatness, voice, energy, and endurance; 2. Intelligence, including ease of learning, capacity to apply knowledge, ability to overcome difficulties; 3. Leadership, including self-reliance, initiative, decisiveness, tact; and ability to command obedience, loyalty, and the coöperation of men; 4. Character, including loyalty, reliability, sense of duty, carefulness, perseverance, and the spirit of service; and 5. General value to the service as a drill master, a leader in action, an administrator, and one who can arrive quickly at a sensible decision in a crisis. Each officer who grades candidates on these qualities is required to construct a personal scale of reference for each quality by writing down a list of five officers of his acquaintance, the first of whom seems to possess the specific quality in a preëminent degree, and the last of whom has as little of it as any one he knows. The third man is then selected as a mean between the two extremes, and the second and fourth as means between the middle and the top men or the middle and the bottom men respectively. The various grades are given numerical ratings from 15 for the highest to 3 for the lowest. The advantages of such scales are apparent, since it is obviously easier to place a candidate on the scale by comparison with other men, than it is to make a numerical estimate of such composite and abstract conceptions as intelligence or leadership. The method has proved so successful in operation that an Army Personnel Committee with Professor Scott in charge has been established as an addition to the Adjutant General's office in Washington to supervise this and other activities involved in sorting, grading, and testing men for all kinds of army work.

The second suggestive method of rating personal qualities as a help to vocational guidance has been used in the University of Cincinnati for a number of years. The characteristics selected for rating in this case are of a very different sort, and are arranged in pairs of related opposites as follows: (*a*) physical strength—physical weakness; (*b*) mental—manual; (*c*) settled—roving; (*d*) indoor—outdoor; (*e*) directive—dependent; (*f*) original (creative)—imitative; (*g*) small scope—large scope; (*h*) adaptable—self-centred; (*i*) deliberate—impulsive; (*j*) music sense; (*k*) color sense; (*l*) manual accuracy—manual inaccuracy; (*m*) mental accuracy (logic)—mental inaccuracy; (*n*) concentration—diffusion; (*o*) rapid mental coördination—slow mental coördination; (*p*) dynamic—static. These pairs of related opposites are printed on blanks, and each instructor is asked to express his judgment of each student by checking one or the other of each pair. The independent votes of the instructors are summarized in the central office. The method of using this type of rating is obvious. No one would think of advising a man of settled, indoor, dependent, self-centred, and static temperament to undertake a job as superintendent of construction on a large viaduct or bridge.

Under present conditions, when current testing and grading systems are more largely estimates of the amount of static information possessed than of dynamic abilities, it is evident that ratings of personal characteristics and dispositions are essential for vocational guidance. Whether this will be so or not when grades have been made to express abilities, whether correlations will be found between various temperaments and various types of ability or not remains an open question for further study. In the meantime there is no investigation that is likely to give larger returns in fruitful progress than the scientific investigation of testing and grading systems; for tests control teaching, and objective records of achievement are one of the most potent means of releasing creative energy in both students and faculty.

Chapter XII

SHOPWORK

In American technical schools shopwork still occupies a rather anomalous position. Few teachers of the mechanic arts have been granted the title "Professor," and the work itself is seldom recognized as being intrinsically of "university grade." Yet no one denies that it is an essential element in the equipment of every engineer; and therefore it has been tolerated by engineering faculties and allowed to develop as best it could. As a result there is no agreement as to the purposes and methods of shopwork. Nearly every school has a shop philosophy and a well-organized shop method of its own.

The first engineering school, Rensselaer Polytechnic Institute, was not financially able in the beginning (1824) to support shops of its own. Therefore the founder directed "that with the consent of the proprietors, a number of well-cultivated farms and workshops in the vicinity of the school be entered on the records of the school as places of scholastic exercises for the students, where the application of the sciences may be most conveniently taught." The students were required in the first three weeks of the first term (page 11) to "examine the operations of artists and manufacturers at the school workshops under the direction of a professor or assistant, who shall explain the scientific principles upon which such operations depend, four hours on each of six days in every week." This plan is identical in principle with that now in use at the Sheffield Scientific School at Yale. There the students spend their whole time for three weeks before the opening of the second year in a well-organized course of this sort called "mechanical technology." The boys do no actual manual work in shops. The purpose of the course as stated in the catalogue is: "to acquaint the student with the terms and processes in use in manufacturing and power plants, and to give him some personal contact with engineering work before taking up his studies in the classroom and the drafting room."

It will be noted that this type of course gives the student opportunity for first-hand observation, study, and discussion of the mechanical technique of production under real commercial conditions, but does not give him either manual skill and the "feel" of the machine that come only from actual use of tools, or acquaintance with the habits and the outlook of workmen. Hence the benefits derived from this work are perhaps more like those derived from inspection trips, the value of which is unquestioned.

A totally different solution of the shop problem is presented at the Worcester Polytechnic Institute. At the founding of this school (1868) the Hon. Ichabod Washburn gave funds with which to establish a small manufacturing plant on the campus. In order to furnish a real shop atmosphere, twenty or more skilled journeymen are regularly employed and articles of commercial value are manufactured and sold in the open market. The students work side by side with these journeymen, but are relieved by them of much of the drudgery that comes from the too frequent repetition of the same operation. The instruction is given by means of a series of graded exercises upon machine parts required for the business of the shop.

In his inaugural address as first president of Rose Polytechnic Institute in 1883 President C. O. Thompson, who originally organized the shops at Worcester, tells us that this work was guided by the conviction that the more the students understand the nature and the difficulties of actual practice, and the more they use theoretical principles under conditions as like as possible to those of real practice, the greater are their chances of becoming competent and successful engineers. Mere contact with practical work, however, is not enough. For the best results the student's work must be subjected to the inexorable tests of business, so that he feels responsibility in the use of valuable materials, and the stimulus that comes from knowing that he is making something that some one else wants but cannot make for himself. Without the construction of articles whose workmanship is subjected to the objective test of salability in the open market, shopwork is liable to exalt the purely abstract aspect of mechanical knowledge.

The shops at Worcester are still run as a manufacturing plant on a commercial basis. But in addition to the regular instruction in shop practice and the construction of articles for sale, much attention is now given there to modern methods of "scientific management." The students analyze the cost of production into its elements, and determine the relative values of different methods of construction to meet the limitations of manufacture and the market price. The organization and operation of the manufacturing work of the shop furnish materials for the study of accounting, time cards, depreciation, inventories, overhead costs, purchasing, and selling.

The Worcester plan, it will be noted, seeks to coördinate the shop instruction with real conditions of industrial production in such a way that the students secure, in the least possible time, manual skill with tools, understanding of the principles of machine construction, and first-hand knowledge of manufacturing and commercial methods. The manufacturing shop is a working model for the study of the technique of business and of practice. The productive nature of the work and the objective test of its salability are two of its important characteristics that tend to make the experience significant to the students.

Among the schools visited, two others, the University of Illinois and Pennsylvania State College, regard the production of salable articles as an essential element of school shopwork. At the University of Illinois the shop has been recently organized as a manufacturing plant for the production of a two-cylinder gasoline engine. No effort is made to market the machine, yet no difficulty has been experienced in disposing of the entire output to the students and their friends. Manual skill is not made a special aim, and there is no series of graded exercises to teach the fundamental operations. The 300 or more operations required for the construction of the machine are all standardized, and instruction sheets, like those regularly used in scientifically managed shops, are carefully followed by the students in all their work. All finished parts are tested and faulty ones rejected.

No paid journeymen are employed, but each section of the class is organized as a working unit, consisting of workmen, foremen, tool-room attendants, production manager, storekeeper, inspectors, etc. Each student is moved periodically from one type of work to another in such a way that when his three semesters of shopwork are completed he has performed all the essential functions of operating the plant.

Each student is graded according to his efficiency in production. Since every shop operation is standardized and has an experimentally set time limit, efficiency is defined in terms of the actual time taken and the standard time. Grades are posted each week and, like all objectively determined grades, they stimulate great rivalry for maximum efficiency. The importance of careful planning and complete utilization of time is forcefully impressed, for the several sections are regarded as rival teams, and no student dares waste time in shop lest his team fall behind.

In this Illinois plan construction is still an integral part of instruction; but the omission of the journeyman mechanics shifts the emphasis from actual commercial production, subject to the objective test of salability in the open market, to instruction about methods of commercial production. The shop becomes a "shop laboratory," and the manipulations there partake of the nature of experiments designed to verify the principles of production that are operative in the industrial world, rather than to solve problems that arise in connection with their productive activities. As in most current laboratory work, the chief problem for the student is likely to be that of following directions intelligently, rather than that of finding the answers to questions that cannot be answered without making laboratory tests.[1]

The shopwork at the great majority of American technical schools is based upon a notion that is very different from those that have just been presented. This notion has existed for many years, but it was given great prominence by President Runkle of the Massachusetts Institute of Technology in 1876. President Runkle was so much impressed by an exhibit of Russian shopwork at the Centennial Exposition in Philadelphia that he immediately addressed a special report on this subject to the Corporation of the Institute under date of July 19, 1876. He explains that in the Russian system all construction has been analyzed into a number of typical operations which may be arranged in groups, each of which involves the use of a distinct type of tool. The novice makes most rapid progress if he is first trained in the so-called "fundamental shop operations" without any idea of making any useful article. Instruction in the use of tools is thus entirely separated from construction or production; so that only after the student has satisfactorily achieved skill in filing, turning, boring, forging, and the like, is he permitted to construct anything. Since the tools

[1] Cf. B.W. Benedict: *Shop Instruction at the University of Illinois. Bulletin, Society for the Promotion of Engineering Education*, vol. vi, pp. 234-257, December, 1915.

required for instruction in the fundamental operations are relatively simple, it is possible at reasonable expense to equip an "instruction shop" that will accommodate as many students as one teacher can instruct at the same time, thereby securing the greatest economy of both time and money. Besides, the more expensive construction shops are not essential at a school, since the young engineer, after graduating in such a course, will find no difficulty in completing his practical education in great manufacturing works.

President Runkle was very enthusiastic about this type of shop organization, calling it "a fundamental and complete solution of this most important problem of practical mechanism for engineers." As a result, instruction shops were established at the Massachusetts Institute and are still being operated with great success as instruction shops pure and simple. The work is now so thoroughly well organized that about 300 hours of training suffices to give a young mechanic skill in the fundamental operations of his trade. The director of these shops, Mr. R. H. Smith, has published his instruction sheets in two excellent handbooks of shop practice.

The inference that President Runkle drew from his study of the Russian exhibit at the Centennial Exposition, namely, that the instruction shops might be totally separated from the construction shops without loss of educational value for engineers, was very generally accepted as sound; so that the majority of college shops were and still are organized on that basis. Undoubtedly the fact that the instruction shops were less expensive to equip and maintain than the construction shops made this division even more attractive at a time when funds were scarce and the financial problem loomed large before the schools. Certain it is that in the great majority of schools there is no direct connection between shopwork and industrial production.

This type of shopwork met a real need when it was first introduced, forty years ago. At that time skill in machine tool work was often a real asset to a young engineer in securing his first job. Manufacturing shops were not so numerous nor so well organized as they are to-day. Under the present changed conditions, the question is now being seriously debated whether the shop courses in the engineering colleges ought to be altogether abolished. This question has been answered in the negative at the University of Illinois by the recent conversion of the shops into shop laboratories designed to teach the principles of industrial production, as just described. On the other hand, the University of Cincinnati has answered it in the affirmative by the establishment of its well-known coöperative plan.

The Cincinnati plan was first formulated by Dean Herman Schneider in 1899, while he was an instructor in civil engineering at Lehigh University. In 1902 Dean Schneider presented a full statement of his scheme to the directors of several large industrial firms which were considering the establishment at Pittsburgh of a new technical school to give an engineering training that would be better suited to industrial needs than that then given in the engineering colleges. This plan was abandoned when Mr. Carnegie founded the Carnegie Institute of Technology in the City of Pittsburgh. Finally, in 1906, Dean Schneider found an opportunity to make his experiment at the University of Cincinnati.

The mechanism of the scheme is very simple. The students are divided into two groups, one of which is assigned to work in industrial plants while the other goes to school. At the end of each bi-weekly period the two groups change places, so that the shops and the school are always full-manned. In the shops the students work as regular workmen for pay, but the nature of their work and the length of time each stays on any particular job are subject to approval by the university. The emphasis of the school work is on theory and principles, but these are well interrelated with the shopwork by "coördinators," who visit each student during each shop period and then meet the several groups during the university periods in special "coördination" classes for this purpose.

The curriculum is completed in five years of 11 months each, so that each student receives 27 months of university instruction. Since the regular four-year curriculum in other schools requires about 36 months of actual instruction, it would seem at first glance that the Cincinnati curriculum could not give as full a training in fundamentals as is given elsewhere. This inference, however, is wholly unwarranted, because in the 27 months of industrial work the student gets a vast amount of practical knowledge which is given in other schools in information courses, and because the close coördination with practice makes the theory more intelligible and significant to the students. The graduates of Cincinnati have unquestionably as extensive a training in theory as have those of other first class schools. In addition, the Cincinnati graduates are able to command engineering positions at graduation without one—or two—year "apprentice" courses, such as are required of men from other schools by a number of the large corporations.

About one hundred of the industrial firms of Cincinnati and the vicinity are now coöperating with the university in this work. These firms represent every important phase of engineering, so that the university is able to arrange the work schedules in such a way that each student progresses regularly thru every phase of his specialty, from the crude and rough work to the more difficult and responsible positions. For example, a civil engineer usually begins with pick and shovel as a member of a gang repairing track. If he elects railroad work, he will progress to switch and signal work, to bridge work, to general engineering work in the engineering department, and to evaluation work. He will learn how to run regular trains and work trains, how to place and operate the equipment for repairs or new construction, and how to calculate cuts and fills—all as part of the regular work on a "real railroad." The employers, on the other hand, also benefit by the arrangement; they have found the labor of the "co-op" students both reliable and profitable.

Financially the coöperative plan is very economical both for the university and for the students. The university has access without expense to shops and shop equipment that are worth millions of dollars and are never allowed to deteriorate or become antiquated. Since only half the students are in school at any one time, the same school equipment is adequate for twice as many students as elsewhere. The result is that the total cost to the university per student per year at Cincinnati is about \$130. At no other school of equal grade is this cost less than \$250, and at the large endowed schools it runs as high as \$600 or even more. The money earned by the student during his shop periods, while not sufficient to pay all his expenses, is of great assistance, and makes possible an engineering education to many a worthy boy who could not otherwise afford it.

In addition to the obvious financial advantage, the coöperative plan has many educational advantages. Not only is instruction combined with construction so that its social use is obvious to the students, but the construction has three marked points of superiority over that done in college shops. In the first place it is real commercial production that must succeed or fail on its merits. A shop atmosphere does not have to be artificially created. In the second place the variety of construction work is much greater than is possible in any college shop. The students' experiences are not limited to those of making a gasolene engine or a drill press, but may include any of the activities of one hundred different manufacturing plants. In the third place the student is thrown into close personal touch with workmen. He thus comes to know their point of view in a sympathetic way and secures a conception of the human problems of industry and of the appraisement of human values and costs that is invaluable to him and cannot be acquired so well in any other way.

Another striking educational advantage is secured by this method of conducting the shop instruction. Because it is obviously impossible for an industrial plant to permit its workmen to spend time giving instructions to green college boys, many have thought that the student must waste an enormous amount of time doing routine manual labor. This loss is prevented by the "work observation sheets" that are given the student when he begins a new job. These sheets contain from fifty to two hundred questions concerning the details of the job, and direct him to sources of information where he can find the answers. He is required to be able to answer and discuss these questions during the "coördination periods." In this way the manual labor is made the source of problems that are solved in the class-room and the laboratories. Shopwork thus becomes a series of exercises in defining and solving problems. Under these conditions it is much more likely to be intellectually fruitful than when it consists in carefully following the specifications of standardized direction sheets.

But if the Cincinnati plan has proved stimulating to the students, it has been revolutionary for the faculty. Coöperation and business methods outside have compelled coöperation and business methods at home, with the results already discussed in Chapter V (page 30). Departmental autonomy has practically disappeared, the spirit of investigation has been liberated in the field of education, and it is probable that more experiments in teaching are being made and objectively checked there than anywhere else.

Dean Schneider's experiment is clearly much more than a novel and inexpensive method of handling the shopwork. It is an effort to create a type of school that meets the demands of an industrial age. It frankly recognizes that the present need is for masters of materials who can humanize industry. It tries to emphasize rather than to discourage the appraisement of values and costs, and endeavors to express idealism in the mechanics of life rather than build ideals that are unrelated to human experience.

Because the educational conceptions on which the Cincinnati plan is founded are so different from the currently accepted conceptions of school practice, it has taken some time for other schools to recognize the significance of the venture. The scheme was scoffed at as unworthy of a real university and more likely to produce skilled "boiler makers" than professional engineers. The graduates are still too young to prove whether this criticism is to any extent valid or not. Meanwhile the coöperating firms in Cincinnati eagerly absorb all the product of the school, while other schools are introducing similar organizations. For several years the University of Pittsburgh has been coöperating on the same principle with a number of firms, the new municipal university at Akron is organized as a coöperative school, and the Massachusetts Institute has just completed arrangements whereby juniors and seniors in chemical and electrical engineering spend a number of months under school guidance in industrial plants before graduation. A detailed account of the Cincinnati Coöperation System, written by Professor C. W. Park, has been published in Bulletin 37 for 1916 by the United States Bureau of Education.

With such rich opportunities for education lying plentifully about in every industrial plant, it is a striking anomaly that the schools make so little use of them. The situation is all the more impressive because the coöperative use of industrial plants results in a large reduction of the cost of schooling and gives the student the chance to support himself partially in college. The neglect of the possibilities of shopwork is responsible in large measure for the professional criticism that the graduates cannot apply theory to practice, for the establishment by large corporations of apprentice schools in which engineering graduates may complete their training on the practical side, for the preference shown by many firms for shop-trained rather than college-trained men, and for the insignificant percentage of production managers who are college graduates.

On the other hand, the neglect of shopwork is not the result of carelessness or of chance. It is due to a consistent effort to meet the professional demand that emphasis in school be placed on the fundamentals of engineering science. But while practising engineers are unanimous in this demand, they recognize that something is wrong with the present system. The fundamentals that are presented in college do not seem to be mastered in such a way that they function readily in practice. Yet common sense instinctively feels that there is no essential contradiction in the practitioner's position, but that it is possible for colleges to teach the principles of science and develop a scientific attitude of mind in such a way that both are readily transferable to practice.

The University of Cincinnati endeavors to do this by using the practical problems of the shop as the basis of the theoretical work in the school. But the established engineering schools hesitate to approve this solution. In spite of the fact that their real aim is to develop men for intelligent production, they fear too close an intimacy with industry. They shrink from offering short courses and extension work in mechanic arts, like those which have done so much to advance agricultural production, because this type of instruction does not seem to be "of university grade." This fear is justified so long as shop practice is limited to training in the so-called "fundamental shop operations" wholly divorced in "instruction shops" from production and contact with workmen. But when the students are systematically guided, as they are in Cincinnati, by work observation sheets and coördination classes, the shopwork not only develops mechanical skill and imparts practical information concerning shop practices, but it also serves as a source of problems and projects for theoretical analysis and solution in the university classes in physics, in chemistry, in mathematics, in mechanics, in economics, in sociology, and even in ethics. The problems thus defined are not the stock type of book problems that were made up to illustrate theories already demonstrated in class; they are the real engineering problems of production that constitute the warp and woof of the engineer's life. On this basis shopwork is perhaps the most effective type of professional training, since it is a direct application of the adage — Learn to do by doing.

Recently Dean Schneider has been able to express this fundamental educational conception of the coöperative system in a manner that is easily comprehensible to university men. Several of the industrial firms coöperating with the university are supporting industrial research laboratories for the purpose of increasing production. These laboratories are treated by the university exactly like every other section of an industrial plant; so that upper classmen, who have shown ability in investigation by the way in which they have discovered and defined problems in industry during their earlier years of shop experience, are assigned here as assistants on research problems for their regular bi-weekly industrial tasks.

During the past decade a number of large industrial companies have established in their plants research laboratories manned by eminent scientists of pronounced research ability. These laboratories are supported by the industries, and are excellent investments, because the increase in the efficiency of production resulting from their labors saves each year more than the cost of their maintenance. Now that increased production has become a national necessity, a large amount of attention is being given to the question of the relation between the universities and the industries in the matter of research. Up to the present the Mellon Institute at the University of Pittsburgh is the only instance of coöperation between a university and the industries in the maintenance and operation of a strictly research institution. The success of this experiment, originally devised and inaugurated by the late Robert Kennedy Duncan at the University of Kansas, has been so gratifying to the university in bringing its professors in contact with industrial life, and to the industries in reduced costs of production, that other similar institutes will undoubtedly soon be established under the pressure of the present great national need. Industrial shops are literally bursting with problems that call for scientific investigation of the highest order; factories are filled with masses of observation and of empirical data whose coördination and theoretical analysis would be of the utmost value to production if scientists competent to accomplish the task could be found. Millions of dollars are annually wasted in the United States by the duplication and repetition of investigations and experiments in several different plants because there is no pooling of problems or of scientific interests and no central bureau of information, record, and research to which all could look for scientific enlightenment. The missing link is a technique for coördinating learning and labor so that each may serve the other to the fullest in increasing the intelligence and the economy of production as the basis of mutual strength. The experiments with coöperative shopwork at Cincinnati and with industrial research at the Mellon Institute at Pittsburgh are rapidly developing such a technique. The engineering colleges are beginning to grasp the real educational significance of coöperative shopwork, and industrial research laboratories at universities will surely be forthcoming as soon as the conception of their national scientific and industrial importance is clearly defined. Some combination of the two will undoubtedly supply the ultimate solution of the problem of shopwork in engineering education.

PART III

SUGGESTED SOLUTIONS

Chapter XIII

THE CURRICULUM

In the preceding five chapters the larger problems of engineering education are discussed and a number of suggestions are offered concerning methods of investigation that promise progress toward effective solutions. It remains to indicate how the various conceptions presented may be integrated in a consistent and workable curriculum.

The question of admission requirements is treated with sufficient detail in Chapter VIII. If a group of schools will take up the careful study of their entrance systems and make experiments with objective tests and records of the students' youthful interests and achievements, it is certain that the percentage of elimination can be reduced to at least a fourth of its present size, with an enormous saving of time, energy, and money for both student and school. The effect on secondary education would also be most salutary, in that objective entrance tests that measure ability require a shifting of the emphasis in high school from learning facts to developing ability, and tend to liberate teachers from the bondage of detailed syllabi and cramming methods. In order to accomplish these ends it is necessary to expand the recorder's office into a bureau of investigation, and to equip it with a competent personnel for this work; for at present most college record offices are overburdened with routine work and so cannot undertake this experiment without both expert guidance and additional clerical help. It is more than probable that the expense thus added will prove a real economy, because intelligent selection of students at entrance is bound to reduce the waste that comes from trying to teach engineering to boys who have no real engineering interest or ability.

The reorganization of the college curricula to accord with the suggestions in the preceding chapters requires several radical changes from current practice. In the first place the number of required credit hours per week should be less than eighteen — preferably sixteen. This recommendation is not intended to decrease the number of hours of work done per week by the students, but to make it possible for them to do all of their work more thoroughly. It is, of course, obvious that such a reduction of required credit hours cannot be satisfactorily made without extensive changes in the content of the courses, for it would be disastrous to leave the distribution of time among the departments as it is and merely try to organize them on a sixteen-hour-a-week basis instead of on a twenty or twenty-four hour basis.

Reduction in amount of work

In the second place, the few experiments that have been made on the subject indicate that college students do their best work when the number of different subjects studied at a given time is not greater than five. In constructing a curriculum it is desirable, therefore, to limit the number of simultaneous courses to four or five at the outside. At Rensselaer they are limited to three, but the advantages of this are to a certain extent offset by frequent changes in the three (page 25).

Reduction in number of subjects.

A third essential requirement of all engineering curricula is adequate provision in the first two years for "orientation," contact with real engineering projects, and practical experiences that make the boy feel that he has actually left high school and entered upon a professional career. Orientation lectures to freshmen meet this requirement to a certain extent; practical work in surveying parallel with trigonometry during the first term of freshman year is perhaps more effective for this purpose; a course in mechanics, such as is now given to freshmen at the University of Washington (page 58), is excellent; but the coöperative system at Cincinnati (page 78) is the most complete and thoroughgoing solution of this problem yet presented.

Practical engineering work is essential for the freshman not only because it appeals to his professional ambition, arouses his enthusiasm, and gives him training in practice, but also because it helps him to master the theoretical work more fully and more quickly. Every one knows that at present the engineering professors are seriously handicapped in their work with juniors and seniors because the students are notoriously unable to make professional use of the principles of physics, of mathematics, and of mechanics with assurance and accuracy. One of the most common complaints of employers is that even college graduates have serious difficulty in applying theory to practice. As has been pointed out (page 80), this weakness may be overcome by suitable coördination of theory and practice during the learning process. Hence to the three other requirements of effective curricula must be added this need for interrelation between the concrete and the abstract throughout the entire college course.

Besides the four requirements that have been mentioned there are a number of pertinent suggestions that demand attention in framing curricula. Thus there is a widespread agreement among professional engineers that the college curriculum should aim to give a broad and sound training in engineering science, rather than a highly specialized training in some one narrow line; that considerable attention should be paid to humanistic studies like English, economics, sociology, and history, not merely because of their practical value to the engineer, but also because of their broad human values; and that the young graduate should have some conception of business management and of the most intelligent methods of organizing and controlling men.

It is well-nigh impossible to construct curricula that will meet all of these requirements and suggestions without giving careful consideration to many of the recent investigations of experimental psychology and to the rapidly increasing literature of the new science of education. Every professor who takes a responsible share of this work will find much to help him in the books listed in the Selected Bibliography on page 127, for until college faculties appreciate the necessity for experiments in teaching and grasp the significance of the results already obtained, progress is likely to be slow. Therefore the first step for any school desiring to reorganize its curricula is the appointment of a small standing committee composed of men who are interested in the problem of better teaching and able and willing to give considerable time to the work. This committee will need ample facilities in the way of clerical help, and effective service on it will soon be recognized by everybody as one of the surest and most expeditious ways of winning academic advancement. Unless a school is prepared to place this study of education on a basis of unquestioned respectability, it is just as well to continue the present methods of constructing curricula by debates on the time schedule and of measuring educational progress in terms of hours plus a passing grade.

When a suitable committee on instruction has been appointed and given adequate support, its first big problem is that of the relations of the school with the industries. Here the solutions are bound to be varied because, tho there is general agreement that some actual experience in practical work is an essential part of the training of every engineer, the environments of the schools are so different that no single type of arrangement is likely to prove most effective for all. Even in industrial centres like Cincinnati, Pittsburgh, and Boston, quite different schedules for handling coöperative shopwork are in use; and still others may be found that are more effective for institutions in rural communities, like Cornell, the University of Illinois, or the University of Colorado. The important point is that in some way adequate provision be made for personal participation in industrial work, for supervision of that work by the school, and for stimulating the student to be ever on the watch for practical questions and problems which may be brought back to the school for discussion, theoretical analysis, and solution. Professor Thorndike found from his study of engineering college freshmen that 95 per cent of them do engage in productive labor; so the problem is to make the time so spent fruitful by some form of supervision that may prevent their wasting their energies as ushers in theatres or bell boys in hotels for the sake of supporting themselves in college.

Having selected the type of coöperative industrial work that seems best suited to the peculiarities of the environment of each particular school, the committee on instruction may proceed to formulate a curriculum for the school work itself. In this it is conceivable that the schools will reach conclusions that are more similar to one another than is probable with the coöperative industrial work; for if it is agreed that the chief function of school work is to give the greatest possible mastery of the essential principles of engineering science, then there is a common foundation on which all curricula must be built. The first step, therefore, in framing a course of study is to define this common basis of all engineering as clearly as possible; that is, to make a list of all the facts, principles, and processes that are essential elements in the equipment of every engineer. Theoretically this is the plan on which present curricula are founded, for they all have a common core made up of three distinct parts, namely, science (mathematics, chemistry, physics, and mechanics), mechanic arts (drawing and shop), and humanities (English and foreign languages). All of this common core is usually explicitly required of every student, no matter what specialty he may choose.

In addition to this explicitly recognized core of common material it is customary at present to require civil engineers, for example, to take brief courses in mechanical and electrical engineering, since it is necessary that a road or a railroad builder know something of steam machinery, turbines, electric machinery, and gas engines. Conversely, the modern electrical engineer must know something about steam engineering, girders, trusses, factory construction, and even tunneling; and the sanitary engineer finds it necessary to understand at least the elements of hydraulics and the mechanism of pumps and pumping machinery. This instruction in one specialized branch of engineering for students who are specializing in another is now generally supplied by technical courses in the third or fourth years, sometimes by combination courses required of all students, and sometimes by special short courses in one branch for students in the others. Evidently there is a large amount of material which is now presented in technical courses after specialization has begun, but which is really essential to every engineer, and therefore might well be explicitly recognized in the core of common material.

Without regard to the question as to whether the subject-matter of this common core is well or poorly chosen and irrespective of the success with which the work is given, there is a fundamental difficulty in the current organization of the common core of all engineering; namely, the fact that it recognizes no inherent or intrinsic relationships among the three categories under which the classification is made. The sciences are usually treated as sciences pure and simple without regard to their function in engineering (page 39); in the mechanic arts the instruction shops are as a rule purposely separated from the construction shops (page 78); and the humanities generally strive consciously and vigorously to get away from engineering in order that the student may get at least a glimpse into the mysteries of language and of literature and a touch of culture. As a result of this lack of inherent connection, many schools have already dropped the requirement of foreign languages, because some faculties recognize that French and German when taught as they are for purposes of drill in grammar have no vital connection with engineering. Similarly some schools are seriously considering giving up the shopwork, since it is not at all clear why skill in the handling of tools is essential to every engineer. There has even been some talk of ceasing to require calculus of every student, because there is very little obvious connection between some forms of calculus and engineering. Thus before a more effective common core for all engineering curricula can be constructed, it is necessary to adopt a classification of the subject-matter that obviously expresses the intrinsic relationships of the several component parts to the needs of every engineer.

The categories for a new classification of this kind may be deduced from the fundamental aim of engineering. As has been frequently pointed out (pages 3–8), the real purpose for which engineering schools were established is to increase industrial production, because the ultimate aim of engineering is more intelligent production. But every production project requires the coördination and adjustment of three factors, namely, scientific theory, mechanical practice, and cost. A theoretically perfect machine that cannot be built is no more useless than one that costs so much that no one is willing to buy it. Success in engineering comes to him who most often judges soundly concerning the best adjustment of these three complex factors. Therefore engineering education is likely to be more effective in proportion as it fosters the development of skill in determining the most expedient adjustments among theory and practice and cost.

It is customary in designing curricula to keep these three essential phases of engineering distinct from one another and to teach them as independent units, leaving their synthesis into well-organized mental processes to the student's own efforts. This practice is so widespread that its validity is naïvely accepted as a matter of course, and few seem to suspect that it may be connected in any way with the year or two of floundering thru which most graduates pass after leaving college and before finding themselves. Universal experience, on the other hand, seems to indicate that the most effective method of learning is by doing; so that if engineering depends ultimately on power to interrelate theory and practice and costs, a training that requires the student frequently to interrelate these three fundamental factors is likely to yield a better product than is secured from a training that largely ignores their interdependence. A curriculum that recognizes the intrinsic relationships involved is not difficult to construct after the fundamental common elements of all engineering have been selected; but until these elements have been chosen, it is impossible to give more than a general outline or skeleton, on which any school may easily construct a program by filling in with subject-matter appropriate to its environment and its educational aim.

A curriculum that satisfies all of the requirement mentioned above would include at least four types of work. In the first place there must be actual participation in real industrial work, either during summer vacations or better thru some form of continuous coöperation with industries. This industrial experience must be supervised by the school and used as a source of problems and projects for scientific analysis and study in laboratory and class-room. It should begin at the beginning of the freshman year and continue at least until the work common to all branches of engineering is completed. In the later years it may well take the form of coöperative work with an industrial research laboratory (page 82). It is not necessary or desirable that all students do the same type of thing, provided class meetings are held for the discussion and exchange of experiences.

In the second place there should be engineering laboratory work, including drawing and descriptive geometry; and this, too, should continue throughout the common portion of the course. Here the student would make the measurements and carry out the operations needed to enable him to solve the problems and projects that originate either in his industrial or in his class work. These problems and projects should be as far as possible framed in such a way that the desired solution cannot be secured without making the experiment; they should not consist of mere verification of known results or of repetition of standardized manipulations. Elementary surveying is a fruitful source of problems of the right kind; the energy transformations and efficiencies of different sorts of machines, prime movers, and motors require endless investigation, much of which is simple enough for freshmen yet rich in engineering content. Questions concerning the kind of material to select under given conditions of stress, wear, and cost are also excellent. Attention has already been called to similar problems now in use in mechanics (page 58) and in chemistry (page 61). All of this material should require the constant use of the fundamental principles that every engineer must know, and frequent problems involving the computation of relative costs under various conditions should be discussed and solved.

The third type of work essential to the new curriculum is mathematics and science, which should be developed systematically in logical order so as to furnish the backbone of the course. The determination of the sequence of topics for the laboratory projects and for the classes in mathematics and science offers an opportunity for investigations of the highest order, because it is obviously desirable that theory and experiment be closely interrelated, and this requires agreement as to what are the fundamental conceptions of mathematics, mechanics, and physics. The Society for the Promotion of Engineering Education has made an admirable beginning of such investigations thru its committees on teaching mathematics and on teaching mechanics; but the reports of these committees have not yet been generally accepted, and the laboratory side of the problem has not yet received serious attention.

The humanistic studies make up the fourth type of work essential to the training of every engineer. The professional criticisms of the schools indicate that this field offers the greatest opportunity for effective changes in current practice, because lack of good English, of business sense, and of understanding of men are most frequently mentioned by practising engineers as points of weakness in the graduates of the schools. The criticisms point out two types of weakness, namely, lack of technical facility in expression, in business, and in handling men; and lack of appreciation of and interest in literature, economics, and social philosophy. Clearly the humanistic departments are not alone responsible for these weaknesses, for no amount of drill in the technique of language will make a student write and speak clearly if he does not think clearly; and training in clear thinking is as much the function of the teachers of science, mathematics, and engineering as it is the function of the teachers of English. And if the professors in the technical subjects rigidly exclude from their instruction all discussion of human values and costs, is it reasonable to expect the students to appreciate economics and social science? As every one is aware, languages, economics, and social sciences are generally treated as "extras" in curricula, and are as generally regarded as superfluous "chores" by the students.

The difficulty in present school practice evidently lies in the exclusion from the technical work of all consideration of the questions of human values and costs; and, conversely, the isolation of the humanistic studies from all technical interest. The theory has been that engineering at best is tied to materials; but that it can be made less materialistic by ignoring the question of dollars and cents in the technical work, and by teaching science, mathematics, economics, and literature for their own sakes entirely isolated from inherent technical relationships. This conception, however, is gradually giving way, for the experiments described in the last four chapters indicate that technical work is more impelling, and is, therefore, more fully mastered, when it includes the consideration of values and costs; while humanistic work becomes significant, and therefore educative, when it starts from and builds upon the professional interest. And after all, the ultimate control of all engineering projects, as of all activities, is vested in some man's decision that the game is really worth while; and this control is likely to be more salutary, the more completely the man who decides comprehends the full import of the values and costs involved.

A good example of one method of treating the study of English so as to develop skill in expression, appreciation of literature, and a philosophy of values and costs may be found in Professor Aydelotte's experiment with freshmen and juniors at the Massachusetts Institute (page 63). If work of this kind were continued thru several years, it might readily be made to include some study of all the political, economic, and social problems which every engineer is compelled to meet. The experiment of organizing a series of projects and problems in these subjects for class discussion, outside reading, and report, into a consecutive course that would give young engineers some conception of the present social situation and of the engineer's relation to it, is well worth trying. It may be that such a course, by developing in students an intelligent understanding of the meaning of engineering in modern life, would be a powerful factor in defining the status of the engineer and in liberating his creative energies for still larger service.

The best time schedule for a curriculum built along the lines suggested cannot be determined in advance. It is therefore necessary at first to make an arbitrary distribution of the 15 credit hours available and then make adjustments as experience may dictate. Two schools, Brown University and the University of Washington, are trying a new curriculum of this kind this year. At Brown the time of the freshman year is divided in this way: mathematics 4, drawing and descriptive geometry 3, engineering mechanics 3, English 3, and chemistry 3. If military science is required, it might be well to reduce the time for mathematics from 4 to 3 in order to make place for it.

It is also impossible to decide without experiment how many years will be required to give this training in the essential common elements of all engineering. After the essential topics have been selected, as much time as is required to teach them thoroughly should be taken for this purpose. Two years may be enough, but if this is found to be inadequate, more should be assigned to this fundamental portion of the work. The important thing is that the essential elements be first selected and then that time enough to master them be given, instead of the current practice of assigning the time and then "covering" as much as is possible within the set limits. No time schedule of the proposed curriculum is offered here, lest schools be tempted merely to fit present courses into the suggested schedule without first making the thorough analysis of the problem here demanded. Such a simple rearrangement of the old bricks in a new pattern will not be likely to accomplish the required results.

No provision is made for foreign languages in the curriculum just suggested. They have been omitted because three-quarters of the 1500 practising engineers who replied in writing to a question on this subject agreed that they had never found foreign languages essential to their professional careers, and half of them thought that they should not be required. In addition, there is a growing conviction among the schools that for students of engineering the time now spent in college on foreign languages may be much more profitably spent in other ways. If it appears that the foreign expansion of the national outlook necessitates facility in one or more foreign languages, every effort should be made to ensure the acquisition of that facility before entering college. At West Point the cadets acquire all the control an engineer needs over French in 200 hours of intensive training; and the technically minded student is far more likely to become broad-minded and cultured thru studies of literature and social conditions in the manner just described than he is thru the type of linguistic drill that is now universally given under the name of foreign languages in high schools and colleges.

The organization of curricula here proposed is very different from that in general use. Therefore it would not be wise to attempt to produce a curriculum of this kind by merely substituting, say, engineering laboratory for foreign languages and the new type of English for the old, without in any way changing the content or the methods of instruction of the other courses. The new plan is based on the proposition that it is possible to analyze engineering practice and to make a list of all principles, facts, and theories that are essential to the equipment of every engineer, and then to organize this subject-matter into a curriculum in which the several types of work are interrelated in such a way that their inherent relations are obvious to the learner. Such a curriculum satisfies the professional demand for broad and fundamental training for all engineers and renders superfluous the requirement of two or three years of pre-engineering work in a college of liberal arts. It does not prepare specialists, and hence specialization is the topic of the next chapter.

CHAPTER XIV

SPECIALIZATION

THE preceding chapter suggests methods that may be profitably employed in framing a well-coördinated curriculum designed to give all students of technology a broad and solid foundation in engineering science and practice, thru personal contact with industrial work, experience in solving practical problems in the engineering laboratories, systematic instruction in mathematics and science, and thoughtful consideration of the significance of human values and costs. The criterion by which to determine what subject-matter may be included and what excluded is that of common necessity; so that all those principles, processes, facts, and theories which are approved by a board of expert judges as essential to the equipment of every engineer are included, and all others are excluded. The course of study thus organized will be called the common core of the curriculum. How may provision best be made for specialization when a student has satisfactorily mastered this common core?

Evidently the first step toward successful specialization is intelligent sorting of the students, so that each is led as definitely as possible into that type of work for which he is best fitted temperamentally. This requires that while the students are working thru the common core of studies every effort be made to discover the particular abilities and specific bent of each, not only by means of ordinary examinations and academic grades, but also thru objective tests of graded difficulty (page 50), personality estimates by members of the faculty (page 73), consideration of boyhood interests (page 53), and observations of each student's reactions to the different portions of the common core. In other words, the work of the common core offers an excellent chance for vocational guidance; so that the student would not choose but rather be claimed by the special field for which he is best fitted. Probably nothing would contribute more to the success of the later specialized work than a systematic utilization of this opportunity. A number of schools are ostensibly doing this now, but none has yet achieved the degree of success that is easily attainable by intelligent experiment with the various methods now in use in many places.

By the methods provided for sorting the students during the first two or three years of their courses it should be possible when they finish the common core of the engineering curriculum to divide them into five or six groups, each of which contains all who have special qualifications for one of the major lines of professional work. For each such group a curriculum must be framed on the same plan as that used for the common core. Thus for the civil engineering group a competent committee would first select all the elements essential to all civil engineers but not already included in the common core, and these essential civil engineering elements would be organized into a consistent curriculum composed of the same four types of work required for the common core. A similar selection of subject-matter has to be made for the mechanical engineering group, for the electrical engineering group, and for each of the other major groups which the school desires to develop.

As with the common core, so here, the amount of time needed to master the materials selected as essential in each group has to be determined by experiment. It may well happen that more time is required for electrical engineers than for civil or mining engineers, but this is no real objection; the conception that four years of study makes any kind of an engineer is a habit rather than a rational conclusion. If the subject-matter chosen can all be shown to be really essential, and if the instruction is intensive, then the school may well insist on time enough to do its work thoroughly. This does not mean necessarily that more than four years will be required for thoroughgoing training, for the present congestion of curricula is in large measure due both to the presence of subject-matter which cannot be justified on the ground that it is essential, and to the teacher's habit of underestimating the student's actual ability and capacity for significant work.

The number of these semi-specialized groups at any one school may well depend on the location and the capacity of the school. The great majority of institutions will probably have one for each of the commonly accepted branches, as civil, mechanical, electrical, and chemical engineering. The mining group has already been somewhat separated from the others by the establishment in mining districts of state schools of mines, so that a number of strong schools elsewhere no longer offer courses in mining engineering. While it is clear that every technical college should offer the common core, it is an open question how many of the semi-specialized groups each should attempt to supply. It is conceivable that some schools might do much more thorough work if they followed the example of Stevens Institute and specialized on one or two groups. It may even happen that a number of the smaller schools will find it to their advantage to give only the common core and send their students for specialization to the stronger schools. It may also be best for many of the students to leave school when they have completed this general work, especially if leaving should be dignified by the award of a suitable certificate or diploma.

On the other hand, there is an urgent need that a number of the schools add to these semi-specialized groups one in production engineering or engineering administration, as it is called at Pennsylvania State College and the Massachusetts Institute of Technology. The seriousness of this need has been emphasized by war conditions, which have demonstrated how essential it is to apply engineering methods to accounting, to the management of men, and to the organization of business, if maximum production is to be attained. Until recently most schools have specialized in design, with the result that at present fully ninety-five per cent of the production managers in manufacturing plants are not college but shop-trained men. The opportunity for the college-trained engineer is now very much larger in the field of production and administration than it is in the field of design, so that the most striking development of the engineering schools in the next twenty years will probably be made in the direction of the former.

Throughout the period of semi-specialization it is desirable to continue all of the four types of instruction comprised in the common core, but the technical work of the several groups may be very different, each along the line of the group specialty. In the humanistic work, however, the subject-matter presented may well be the same for all, because the engineering attitude which these studies foster is the same for all. By this means it is possible to develop among the engineering students a unity of purpose and outlook which will be a great asset in developing a professional consciousness among engineers, because it tends to establish engineering standards by which to interpret and attack the industrial and social problems of the day.

The systems of grading and personality analysis used during the early portion of the course should also be retained, in order that the semi-specialized work may furnish the basis for more accurate guidance of each student into the particular line of work for which he is best fitted.

When the student has completed the semi-specialized work he should be well grounded in the fundamental principles of engineering science and in the theory and practice peculiar to some one of the major branches of the profession. If during this training he has shown particular ability in some specific line of work, opportunity should be given him to pursue his specialty in elective courses of highly technical content. These courses, however, should not consist, as many of the senior electives do now, of detailed study of the technique of such subjects as heating and ventilating, telephone wiring, roads and pavements, sewage disposal, and the like. If the student has been trained as he should be in methods of attacking problems and gathering information, he will probably make better progress in this kind of work in the industries than he will in school. Since these courses are for specialists who have elected them after a long process of vocational selection, they should deal with the more abstract and general phases of each subject. For the industrial phase of it, current problems in industrial research with practice as assistant on some of them are appropriate; for laboratory practice, expert testing and trouble hunting might serve well; on the scientific side, thermodynamics, the ionic theory, differential equations, functions of a complex variable, wave motion, spherical harmonics, electromagnetic theory, and all types of design, might be given for those whose bent and abilities warrant.

The plan of curriculum here proposed may seem to many very similar to the one on which curricula are at present constructed. In a general way this is true, since both the present plan and the one proposed agree in requiring all engineers to take the same training at the beginning and in gradually separating them into specialized groups later. The two schemes, however, differ radically in a number of important ways. In the first place, current curricula are made by first setting the time limits for each of the several subjects involved and then allowing each department to use its time allotment as it may see fit (page 56). The new plan suggests that the faculty first select the subject-matter that is essential to the equipment of every engineer and then ask the several departments to determine experimentally how much time is needed for their respective parts. The former is a centrifugal system, which magnifies departmental differences, causes confusion as to the aims of the instruction, and wastes an immense amount of time; the latter is centripetal, in that it operates to bring about mutual understanding and hence definiteness of aim and economy of time.

Again, the proposed plan calls for the student's participation in real industrial work and the utilization of his experiences there as a source of problems for theoretical analysis and solution in the class-rooms. This is suggested as a substitute for most of the current shop practice, such elements as should be retained in school being included in the engineering laboratory work.

In the third place, the suggestion is made that engineering laboratory work be required throughout the first two or three years. At present such work is given almost entirely in the last two years, because teachers generally believe that the students are incapable of working intelligently at practical engineering projects until they have been well drilled in theoretical principles and mathematical processes, in spite of the astonishing manner in which boys of high school age learn without assistance to manage wireless telegraphy or gas engines. The proposed arrangement makes it possible for the faculty to assign tasks that tax the boy's capacity and challenge his ingenuity and his natural instinct for mechanism. Such tasks are almost sure to be effective means of releasing creative energy and of directing it so that it brings the greatest educational returns. Besides, under these conditions a student finds himself constantly in need of the principles and methods developed in the classes in mathematics and the sciences. In this way these subjects may be made significant to boys with an engineering bent; and, as is well known, the probability of learning thoroughly increases with the significance of the lesson. The fact that a boy elects engineering indicates that his mind is probably of the type that thinks most clearly in terms of specific objects, and that grasps general principles most firmly when it has built these up by the synthesis of a number of specific concrete cases. In combination with the coöperative industrial work this engineering laboratory work furnishes also a rational foundation for the proposed industrial research of the later years (page 82).

In the fourth place, the suggested organization requires a close coördination between the scientific courses of the common core and the practical work. At present mathematics and the fundamental sciences are usually taught for their own sake, with independent laboratories and little attention to technical applications. Under the arrangement proposed the essential portions of the laboratory work in elementary physics, for example, would be absorbed and taught in the engineering laboratory. The elementary class work in physics would then be limited to the study of those fundamental conceptions and principles of physics that are embodied in all engineering work; while the more elaborate and recondite portions of the subject would be reserved for elective courses in the later years, where they would be better appreciated by students qualified to grasp their significance. The same suggestion applies to chemistry and especially to mathematics, in which much that is ordinarily imposed on unwilling sophomores would be eagerly grasped by selected seniors.

A fifth departure from current school practice is made in the recommendation to emphasize the problems of values and costs. This topic has obtained scant recognition in higher education for fear of contaminating university ideals with those of the marketplace. Such a fear is justified when the discussion is limited to monetary values and costs. But when the subject is treated in some such manner as Professor J. A. Hobson treats it in his *Work and Wealth, A Human Valuation*,[1] it may be made the most potent means of expressing the highest type of university spirit. Hence in urging extended consideration of this subject it is taken for granted that the discussions will not be limited to questions of dollars and cents. The control of engineering lies in the hands of those who judge most accurately what enterprises men value sufficiently to be willing to assume the cost. Because engineering education has confined itself largely to technological training, engineers are seldom placed on state highway commissions and other public boards that must decide how public funds shall be expended on engineering enterprises. Too frequently the engineer is employed to do the technical work of construction only after a board composed of doctors, lawyers, clergymen, bankers, merchants, or politicians has made an appraisement of values and costs and decided which project shall go forward and which not. The conception is rapidly developing that the public interest might be better served if the engineer had more voice in making such decisions, and to win greater influence in this direction he must be trained to appraise correctly what men consider to be most worth while.

Because the appraisement of values and costs is the controlling factor in engineering, the final important change from current school practice that is suggested deals with the humanistic studies. The usual method of treating these subjects in short independent courses in the technique of composition, literature, history, economics, and so on, seems less likely than the method proposed (page 92) to develop the desired insight into these profound problems of value and cost. The experiments at Wisconsin and the Massachusetts Institute have progressed far enough to show how successful this type of work is with freshmen in developing powers of both forceful expression and appreciation of good literature. Therefore it seems reasonable to expect that the extension of this work into a consecutive course extending thru the entire curriculum and consisting of live discussions and extensive study of the best that has been thought and said concerning the immediate and the ultimate values in life, offers the most promising solution of the problem of culture for engineers.

The organization of curricula suggested in the foregoing chapters does not solve the problem of engineering education. It does, however, create conditions that are more favorable than those now prevailing for progress toward the desired solutions of a number of the major questions. Thus objective tests for admission will undoubtedly

[1] Macmillan, 1916.

enable the schools to reduce elimination by permitting only those who have some demonstrable degree of engineering ability to enter, but much time and many experiments will be required before this end is accomplished. Similarly the engineering work in the common core, when measured by a suitable system of testing and grading, makes the experiences of the first two or three years both valuable to technical men of all grades and a further means of sorting the students according to their varying degrees of engineering talent and ability. On completion of the common core an opportunity is given for those whose capacities and temperaments lead them to prefer the practical phases of production to leave school with credit and go to work immediately.

Finally, specialization, which has been the source of so much trouble to curriculum makers, is subordinated in the proposed plan to vocational guidance. Because the common core contains real engineering work, it can be made a measure of engineering ability that is much more searching and valid than is possible with the current abstract, linguistic type of work. And because the common core contains the essential elements of all branches of engineering, it gives the student a chance to choose his specialty on the basis of experience, and furnishes the faculty with a broader range of activities on which to base its judgment of special aptitudes for particular jobs. Hence it diverts the attention of the faculty from the construction of specialized grooves down which the student may be shoved by routine administrative mechanisms, to the study of the personalities, the temperaments, and the capacities of young men who are eager to do the work for which they are best fitted. The required change in attitude on the part of the instructor may be materially encouraged by changing the conditions under which faculties serve along the lines suggested in the following chapter.

CHAPTER XV

TEACHERS

IN the summer of 1824 Amos Eaton was employed by Stephen van Rensselaer to deliver a series of lectures on natural science, with experimental illustrations, at a number of towns in New York State. The undertaking was so successful as an educational venture that a school was founded to train teachers to instruct farmers and mechanics in the applications of science to industrial production. Thus the first American Engineering School owed its existence to the fact that a man of rare power as a teacher had been found to conduct it. Following the inspiration embodied in it by Amos Eaton, the Rensselaer School was for forty years a Mecca for teachers of applied science. The published works of Professor Eaton prove that he was also a scientific investigator of rare merit.

Thirty years later (1853) William Barton Rogers, also a geologist and pioneer investigator of the geology of Virginia, moved to Boston to find opportunity to teach industrial workers how to utilize science in their work. For twenty-five years Professor Rogers had taught natural science at the University of Virginia with such spirit that the aisles and window-seats of his lecture room were often crowded by young men eager to listen to the eloquent words of the teacher they so much admired. It was in this spirit that he founded the Massachusetts Institute of Technology, and the nine men whom he called to be fellow members of the first faculty were all enough interested in the educational problem to give a large share of their time to its study.

The interest in the teaching problem has never disappeared wholly from engineering schools, as it has from some of the universities. The first, and for many years the only association for the study of education in colleges was the Society for the Promotion of Engineering Education, which developed from the engineering congress at the Columbian Exposition in 1893. For twenty-five years this organization has carried on extended and valuable studies in its field, and there can be little doubt that the recent rapid progress in engineering education has been in large measure due to its activities. At present about one-third of all the teachers in American technological schools are enrolled among its members, yet in spite of this, a series of questions on educational aims, methods, and practices, which was personally presented to the faculties at the first seven of the schools visited, proved highly unpopular; and from eighty-five answers that were turned in it appeared that 38 per cent of the professors spend no time at all in study to increase their understanding of educational methods, 60 per cent spend from one to ten per cent of their time in this manner, and but 2 per cent spend more than this. Obviously it is essential to pay much more attention to the study of education if serious progress is desired.

Fifty years ago little was required of the college professor beyond his teaching. The opportunities for participation in industry were relatively few, and scholarship was universally regarded as a valid excuse for the impracticality of academic life. But as industrial production has become more and more scientific, the bonds between the engineering school and the industries have become closer, until now it is generally recognized that intimate coöperation between the business man and the teacher is of the greatest benefit to both, for thereby businesses grow more creative and colleges more business-like.

The infusion of business methods into colleges is of fundamental importance for good teaching. The tradition that scholars and investigators have no interest in the material rewards of their labors is true only with regard to rewards over and above what may be considered as a living wage. It is therefore just as essential for good teaching as it is for good work of any other sort that the worker be relieved of worry over the means of material support for himself and his family. During the past twenty years schools have made very striking progress in the way of stabilizing teachers' tenures and salaries both by larger endowments and appropriations of public funds and by better business management. Nevertheless much still remains to be done; for, tho teachers' pay has been slowly increasing, the median salary for a full professor at state-supported institutions is now only $2500, and his appointment at some schools has to be renewed formally every year. Even at universities where professorial appointments are ostensibly made for life, teachers of distinction and even entire faculties are at times summarily dismissed by the board of trustees.

Two other phases of the problem of laying firm foundations for the profession of teaching have already been the subjects of extended investigation and report by the Carnegie Foundation for the Advancement of Teaching. Bulletin Number Five, on *Academic and Industrial Efficiency*, indicates how modern business methods may be advantageously applied in university organization to liberate teachers from such drudgery as care of buildings and grounds, purchasing supplies, publicity, keeping records, financial management, and supervision of the material welfare of students. At some of the larger schools professors are now free from duties of this sort, but many a university man still spends much time and energy running a typewriter, posting accounts, keeping records, or making out requisitions. Bulletin Number Nine (1916), on *A Comprehensive Plan of Insurance and Annuities for College Teachers*, describes the principles and methods that have been proved by ten years of experience and exhaustive study to be essential to a sound and effective system of insurance and annuities for college teachers. An organization for putting this plan into action has been formed and financed, thereby supplying one of the most essential ingredients of the business basis on which a new liberalized education may safely be built.

The creation of stable financial conditions, the assurance of permanency of tenure, of a living wage, of relief from routine clerical work, and of safe insurance against old age, however, are not the only requirements for encouraging good teaching. Institutions that have already achieved these fundamental prerequisites are still hampered by educational conceptions and practices that discourage rather than encourage progress in teaching. Prominent among the usages that tend strongly to preserve the *status quo* is the common practice of employing large numbers of recent graduates or even of undergraduates as assistants in elementary instruction where the classes are large. These assistants have usually received all their training in engineering schools that pay not the slightest attention to the professional education of the teacher. When such a novice begins his apprenticeship as teacher, his instruction depends entirely on the attitude of the head of his department. He may be turned loose without directions of any kind, or he may be given such minute directions that he is apt to become a cog in a machine. In any case he instinctively imitates the methods and practices of his own teachers, and is kept so busy with routine work that he has neither the time nor the inclination to study or make experiments in teaching. That so many eventually turn out to be good teachers is a tribute to Yankee adaptability rather than to educational foresight, but the energy losses due to inevitable blunders during the teacher's period of incubation are a serious drain on the intellectual output of the schools. In some of the best institutions the number of assistants is greater than the number of full time professors.

In selecting young graduates for assistants in teaching it is customary to pick out those who have won high grades in the subjects they are called upon to teach, because mastery of subject-matter is obviously a first essential for teaching. Several schools, however, have recently recognized that this apparently worthy practice may be a serious handicap both to progress and to good teaching. Under present systems of grading, high marks are quite as likely to indicate adaptability to the professor's point of view, as they are to stand for either mastery of the subject or independence of mind. Hence the inbreeding process, even when based on high grades, in reality tends strongly to maintain a stolid conservatism which deplores innovations and inhibits experimentation.

As a remedy for this condition, at one or two schools appointments to the teaching staff are made only after the candidate has had one or more years of successful experience in some phase of engineering practice. In a few of the more progressive departments no man is ever appointed to a full professorship until he has won the recognition of the technical experts in his own line of work. In this respect conditions may be still further improved by freer use of graded objective tests and of personality ratings (page 73). Schools of engineering might also do well to consider seriously coöperation with departments of education in the professional training of teachers of applied science and in the scientific study of their teaching problems.

While the recruiting of the teaching staff from recent graduates tends to maintain conditions as they are, and therefore to inhibit experiments in teaching, the current indifference of colleges to problems of education is more directly traceable to the lack of effective incentives for this work. After the teacher has been liberated from worry over material support, his most impelling incentive is his desire for self-expression in creative work. Universities recognize this fact, and have for forty years been struggling to develop conditions that would free creative imagination and expand the bounds of knowledge. In this they have been marvelously successful in the field of natural science—so much so, that research and the publication of the results of research have become the measure of success and the criterion of promotion in most institutions of higher education in the United States. So completely has this conception of research won recognition that academic promotion is now determined almost wholly by success in it. This fact has produced the impression, prevalent in many quarters, that research and teaching are in some way antithetical. Hence the question has often been raised whether research should not be discouraged at educational institutions in order that teaching might receive a larger share of attention.

It is unquestionably true that research, as at present treated, does interfere seriously with teaching. Hundreds of college instructors whose interests lie in the human problems of education, rather than in the material problems of natural science, are now being diverted from a study of the teaching problem and induced to undertake research because academic promotion so obviously depends on the latter. Many a young man with promise of making an excellent teacher is sidetracked by the requirements for the Ph.D. degree and becomes instead, a mediocre researcher. Yet tho much that is done under the name of research is but pseudo-research, the university is clearly right in its position that the spirit of investigation is an essential factor of university life.

The difficulty does not lie in research itself, but in the limitations that still cling to the common interpretation of it. Because research has been developed in the field of natural science and has wrought such marvels there, its activities have unconsciously been thought of as restricted to the problems of the material world. Because the technique of research and the units and methods of measurement have been so perfected in the domain of natural science that great accuracy and definiteness of conclusion are now possible, the early struggles for objectively defined standards and scales have been forgotten. Hence it seems to many grotesque to talk about research in education and the impersonal measurement of the vaguely defined and elusive qualities of human beings. The fact that such measurements have as yet been rather crude and inconclusive is no reason against trying to improve them, especially now when the greatest need of education is a technique and a terminology that will make the results of experiments in teaching intelligible to every one. The inability of teachers to carry conviction as to the merits of teaching and the meaning of experiments in education is one of the chief reasons why teaching fails to receive the recognition accorded to research. But as soon as it is possible to measure the results of teaching by impersonal means, successful teaching will be as easy to recognize as profitable research. Objective records of achievement have been found in industry to be one of the best incentives to creative work. Hence the line of progress in education does not lie in the direction of making arbitrary distinctions between research and teaching, but rather in the direction of removing the limitations placed upon the spirit of enquiry so as to encourage its expansion to education and human relations generally.

If university trustees, presidents, and faculties will unite in insisting on a scientific study of their educational work, they will create the conditions needed to release teaching power in the engineering schools. The professors who have teaching interest and ability will welcome the opportunity to win recognition in work that arouses their enthusiasm and stirs their imagination to creative effort just as the professors who are interested in natural science have responded to the opportunity to promote research. This should not result in a diminution of output in research, but in a decided increase, because it tends to give each man the work he is best fitted to do, and therefore leads ultimately to maximum efficiency.

The practical carrying out of this suggestion in any school is relatively simple, provided the faculty is ready and able to undertake it in a spirit of disinterestedness and helpful coöperation, that is, in a real scientific spirit. Many practical hints concerning essential details of operation have been given in preceding chapters. Any faculty that will get together and take time to think out their problem can create an organism that will be a live influence in education; and the doing of it will in two years bring more joy to all concerned than forty years of weary effort to maintain things as they are.

The good effects of an interest in the scientific study of education in institutions of higher learning are not limited to the institutions themselves. For a number of years objective methods of measuring the results of training have been gaining favor in the lower schools. Until very recently the colleges and universities have looked askance at the progress, and refused to do their share by giving professional training to those whom they send out to teach. The colleges have thus been a positive hindrance to this development, and even now, when more than half of their graduates teach, for a time at least, no professional work in education is as a rule required outside of the so-called teacher's colleges. Meanwhile the industries have been compelled by the slowness of the academic development to establish schools of their own, and have organized the National Association of Corporation Schools with an active membership of more than one hundred and twenty-five large corporations, which are as much interested in the scientific study of vocational guidance and methods of training as they are in industrial research. The scientific study of industrial education thus ranks with industrial research as a bond of union between the engineering schools and the industries. On the fuller development of both teaching and research depends the realization of the ultimate aim of engineering education, namely, more intelligent production.

CHAPTER XVI

THE PROFESSIONAL ENGINEER

AT the first meeting of the Joint Committee of the National Engineering Societies with representatives of the Carnegie Foundation for the Advancement of Teaching it was agreed that an analysis of the requirements of the engineering profession was one of the first essential steps in this study of technological education. Accordingly a number of representative engineers were questioned in personal interviews concerning the factors that are most powerful in determining success in engineering work and most effective in building up the engineering profession. These interviews, together with a study of the methods of rating college graduates in several large manufacturing companies, indicated that personal qualities such as common sense, integrity, resourcefulness, initiative, tact, thoroughness, accuracy, efficiency, and understanding of men are universally recognized as being no less necessary to a professional engineer than are technical knowledge and skill.

The statement that individuality counts for as much as learning for the engineer, just as it does for the lawyer or the physician, seems like a veritable platitude. Yet because the engineering schools have always made it their chief aim to impart the technical information needed in industrial production, and because both scientific knowledge and industrial practice have grown so rapidly, the attention of technical schools has been focused chiefly on keeping up to date in science and practice. The university emphasis on research in natural science has also tended to magnify the importance of technique and to minimize the importance of personality; until curricula have become so congested with specialized courses that students generally regard literature and sociology as unnecessary chores, to be endured rather than enjoyed. Therefore it seemed necessary to consider the question whether this emphasis on technique is producing a new and higher type of engineer, or whether the engineering profession still stakes its faith on the fundamental thesis that personal character is, after all, the real foundation for achievement.

The results of this enquiry have already been published.[1] Briefly, they showed that fifteen hundred engineers, who replied in writing to the question: What are the most important factors in determining probable success or failure in engineering? mentioned personal qualities more than seven times as frequently as they did knowledge of engineering science and the technique of practice. A second circular letter stating this result was then sent to the thirty thousand members of the four large engineering societies, and each was asked to number six groups of qualities headed respectively Character, Judgment, Efficiency, Understanding of men, Knowledge, and Technique, in the order of importance which he gave them in judging the reasons for engineering success and in sizing up young men for employment or for promotion.

[1] *Engineering Education*, vol. vii, No. 3, pp. 125–144, December, 1916; *Educational Review*, vol. 53, January, 1917; *Columbia University Quarterly*, vol. xix, pp. 56–73, December, 1916.

More than seven thousand engineers replied to this request, and their votes placed the Character group at the head of the list by a majority of 94.5 per cent, while Technique was voted to the bottom by an equally decisive majority. A very similar definition of the essential requirements of the engineer was formulated by Mr. A. M. Wellington and published by him in the *Engineering News* for May 11, 1893, as the conclusion of his well-known series of articles on the engineering schools of that time.

This definition of the essential characteristics of the professional engineer is important, because it proves that in spite of the enormous development of scientific information and technical skill, the engineers of America have not been beguiled into thinking that efficient control of the forces of nature is the sole requirement for achievement in applied science. Therefore the schools that intend to train engineers cannot afford to neglect wholly the personalities of the students. While it is obvious that personal traits like integrity, initiative, and common sense cannot be taught didactically like the rule of three, it is no less obvious that the growth of these essential characteristics in students may be either fostered and encouraged or inhibited and discouraged by the manner in which the school is organized and the subject-matter presented. The problems of finding the best organization, of constructing the best curriculum, and of discovering the best methods of teaching cannot be solved by logic alone or by research in natural science. As has been abundantly shown in the preceding chapters, their solution requires extended experiments in education under conditions that command respect.

The enquiry just described was completed in 1916—a year that will always be memorable in the history of engineering because it marks the beginning of a deeper public recognition of the importance of the engineer's function in national life. In that year the Federal Government, for the first time in its history, formally recognized the engineering profession in the organization of the Naval Consulting Board, the Council of National Defense, and the National Research Council. The first of these invited the National Engineering Societies to nominate the members of the state committees on Industrial Preparedness which compiled an inventory of the industrial resources of the country. Representatives of these societies are also members of the National Research Council which has so effectively mobilized the scientific resources of the country for national service. The establishment of the Engineering Foundation, the United Engineering Societies, and the Engineering Council, and the recent appointment of one man as secretary of them all, indicates the progress that is being made toward the conception that there is really but one profession of engineering, in spite of its apparent division into the several well-known branches.

War conditions have not only hastened public recognition of the engineer as an expert in applied science and fostered solidarity of the profession, they have also opened to him new fields of activity. Back in 1914 most people believed that the war could not last long because enough money could not be found to finance it. But three years of experience have made it clear to every one that altho money is plentiful, it is useless if there is nothing to buy; so that winning the war depends on increasing production by an amount which has been estimated as the output of at least ten million additional industrial workers. This extra production may be secured either by training more workers or by increasing the output per worker by engineering methods. Hence there has arisen a pressing demand for men who can deal with labor and with business administration in the engineering spirit. This demand is further emphasized by the fact discovered by the Federal Trade Commission, that only ten per cent of the manufacturers in the United States know their actual costs of production. The determination of these costs requires a scientific study of production which only an engineer can make. This work involves the analysis and apportionment of overhead expenses, and thus leads at once to such fundamental questions of economic justice as: Should the capital invested in idle machinery be paid wages tho idle workingmen are not?

These new opportunities for the engineer have been gradually developing for a number of years, but the profession as a whole has been slow to discern them. The war has focused attention on them and precipitated a general recognition of them. It is also evident that the mastery of these new activities depends in greater measure than does mastery of the traditional types of engineering on the personality of the man. The success of a designer of bridges or of machinery is not necessarily impeded by lack of insight into human nature or of failure to comprehend the things that mankind considers most worth while. But to the man who would deal successfully with human labor and with business, personality is usually a greater asset than technical knowledge and skill. Therefore as engineering expands into the new fields now opening before it, the conception that character, judgment, efficiency, and understanding of men are no less necessary than technical knowledge and skill will become more and more impelling, and it will become more and more essential that schools of engineering pay greater attention to the effect of their work on the personal development of the students. Altho many specific suggestions as to how this may be done have been made in the preceding chapters, a connected summary of the educational conceptions on which the suggestions are based may serve to make clearer why the current organization is inadequate and how the proposed plan more fully meets the present requirements and also supplies a sound basis for future growth.

The ultimate aim of engineering education has always been and still is more intelligent industrial production. Technical schools were founded when industrial evolution had progressed so far as to create a pressing demand for men who knew how to utilize the new and rapidly expanding knowledge of natural science to increase and improve production. Science was then little taught in high schools and colleges, so that both the public and the manufacturers were ignorant of it. Under these conditions the obvious need was for scientific enlightenment; and this the engineering schools were organized to supply. President Rogers's statements that the immediate aim was to supply the intellectual element in production, and that this meant knowledge of the fundamental principles of science, were accurately true when he made them (1861).

The schools have loyally pursued this aim, and have thereby contributed enormously to the achievement of two striking results; namely, the extension of science instruction into the school system generally, and the development of public recognition of engineering as a profession, coördinate with theology, medicine, and law. At the present day an encouraging fraction of the people are reasonably intelligent in science, the worker in applied science has become socially respectable, and there has been developed a large conception of the engineering profession. Meanwhile the methods of dealing with the material problems of industry in a scientific way have been in a measure established, while the more intricate problems of organizing and managing men are rapidly pressing forward and demanding engineering treatment.

The net result is that the curricula and methods of instruction that were devised to supply the intellectual element in production by imparting knowledge of natural science must be reorganized to meet the new industrial demand for engineering administrators and the larger professional demand for men of strong personality. The general plan of the proposed reorganization is based upon an analysis of engineering practice into its three essential factors; namely, knowledge of engineering science, skill in technique of application, and judgment in the appraisement of values and costs. In every engineering project the overlapping claims of these three essential factors must be harmonized with respect to the two fundamental elements of production, namely, materials and men. Surely every engineer should have some conception of the present conditions and problems in at least the general aspects of all these essential factors and elements. If this be granted, it is easy for any school to discover where its curriculum is overloaded and where it is deficient.

This analysis also indicates how the present organization of school work can be modified so as to furnish a more vital training for professional engineers. Thus, with regard to materials, the schools do give careful instruction in the laws of physical science and in the properties and uses of materials. Students are taught the relative strengths of substances in the materials laboratory, kinematics teaches the principles of gearing, the shapes of gear-teeth are worked out in the drawing room, the chemical properties are taught in chemistry, mechanics deals with the forces required to overcome inertia, machine work is relegated to the shop, and so on. But seldom is all this information coördinated in a single practical problem, such as determining whether mild steel, nickel steel, or phosphor bronze is the best thing to use in making a particular gear wheel; nor is the student ever asked to judge what combination is likely to produce the most valuable result for the price. Yet this balancing of value and cost is the controlling factor in all intelligent production.

Again, little consideration is given in courses in machine design to the comfort and safety of the operator. Yet a punch press, for example, that requires a workman to use both hands to operate it is far more intelligent than one that takes a large annual toll of fingers because the driver has one free hand. Similarly the importance of good heating, lighting, ventilation, and sanitation in increasing the output of workers and in keeping them strong and healthy should always be taken into account. These human factors enter in large measure into the determination of the values secured for a given cost.

It thus appears that an adequate treatment of the first element in production involves not only a scientific presentation of the laws of nature and the properties of materials, but also an estimation of the values and costs from both the material and the human points of view. The chasm between the school and practical life is due largely to a failure to appreciate this fact. The introduction of the study of values and costs in all their phases is the most direct method by which the schools can bridge this chasm. Such study is also one of the most potent means of liberating creative energy and of developing the spirit of investigation.

With regard to the second element of production—men—most schools at present are doing practically nothing to arouse the students to an intelligent appreciation of the problems of personal and human relations in production. Yet these problems are every day becoming more acute, as indicated by such movements as Americanization, human engineering, industrial engineering, and scientific management, with their various efforts to improve the condition of the workman and to increase his output in production. Many of the burning questions of the time lie in this field. The loss to industry from turnover—the hiring and firing of workmen—is variously estimated at from $150,000,000 to $400,000,000 a year. This expense adds from 7 to 20 per cent to the cost of production, and yet it injures rather than benefits the product. What are the means to prevent turnover—better housing? better social conditions? higher wages? profit sharing? opportunity for self-expression? juster economic treatment? or more kindliness? Does the time-study method of speeding up work pay? Does it really relax or wear out the worker? Does it produce the best type of citizenship among the industrial classes? These and many other similar unanswered questions are now waiting for an engineering analysis, and the country looks to the engineering schools to train men who shall be able to answer them.

The training of men for the solution of these human problems cannot be carried out in the schoolroom alone. The students must have some vital, first-hand, personal contact with labor and workmen's conditions, either by a coöperative system, as at the Universities of Cincinnati and of Pittsburgh, or thru the industrial service movement, or in some other real and living way. Hence meeting this demand requires some form of closer coöperation between the engineering school and the industries, better understanding of their mutual relations, and willingness on both sides to approach the problem with the true research spirit. Such coöperation is needed not only to give the students a vital conception of the workman's point of view, but also to furnish that intimate personal knowledge of the details of production which cannot be secured in college laboratories and shops. The lack of this sense of the physical properties of materials is one of the chief reasons why less than five per cent of the production managers in this country are college-trained men.

It is, however, in the matter of estimating values and costs that this problem assumes its most far-reaching consequences. The following are some of the typical problems now pressing for solution in this field. What is the effect of good housing on the development of the men, the efficiency of production, and the size of the profits? What is the most effective incentive to maximum output —the bonus system? opportunity for coöperation in management? opportunity for creative work? or shorter hours? Does the assurance of justice and a square deal always tend to increase output and also to foster the growth of a social spirit and of patriotism? Does a plant pay better when profits and output are increased by efficiency methods which give workmen no chance for self-expression? or when the development of the workmen is made an aim as well?

Every manager will estimate the values and costs of these various methods of treating workmen in accordance with his own philosophy of life. There is as yet no conclusive evidence to prove these cases one way or the other. The successful manager to-day is the one who estimates most accurately the human values involved. Therefore, one of the most important contributions that the school can make toward the education of the engineer is to guide him in developing an attitude toward life and a philosophy of living that will enable him to judge rightly as to the things humanity considers most worth while. This is the meaning of the professional demand for larger opportunities for cultural and literary studies. It cannot be met by merely requiring more work of the ordinary academic type in history, in economics, and in languages; but rather by introducing the consideration of values and costs into the regular engineering instruction in some such way as that described in Chapters XIII and XIV.

Some attention has already been paid by the engineering schools to the problem of organizing men into effective working groups. At the Massachusetts Institute of Technology, Pennsylvania State College, and several other schools special courses in engineering administration are now given regularly. These courses deal mainly with the various types of organization, the technique of different kinds of management, accountancy, banking methods, and economic theory. All of this is, of course, essential to every engineering administrator. Industry sorely needs men thus trained; for the determination of costs is relatively easy so far as materials and labor are concerned; but the overhead, because it includes the cost of maintaining the organization, is a matter of great difficulty. Analysis by engineers shows that the largest wastes in production are in the overhead expenses, and result from faults in organization, such as idle machinery, inefficient maintenance, poor routing, lack of foresight in purchasing, delays from lack of instruction from the office, and so on. The study of overhead expenses has led to many searching questions of economics and industrial justice, with which the student will have to deal after graduation, but to which the schools have not yet given serious attention.

But it is gradually becoming evident that the ultimate success of any organization depends on its spirit; and this, in turn, is determined by the manner in which those in control coördinate and interrelate the intelligences and imaginations of men. Great organizers and leaders in industry are those who not only master the laws of nature, but who also shape and control their organization thru their power of estimating accurately the value which each worker esteems most highly. The engineers instinctively recognize this fact and the educational implications of it when they declare that character, judgment, efficiency, and understanding of men are even more essential to the practising engineer than is knowledge of the science and technique of engineering.

The educational interpretation of this professional demand is not nearly so mysterious as many have tried to make it. For the schools have already discovered that students learn best when they are inspired by the conviction that the work is really worth while. One of the most effective ways of making work seem worth while is by constantly relating it to the consideration of the whole range of values involved and all the costs. Every decision in daily life is an answer to the question whether the value is worth the cost. The omission of this mainspring of all investigation and enquiry from school work is perhaps the chief reason for the breach that separates the schools from life. Hence the first message of the profession to the schools is—Motivate your work by making it worth while; liberate the spirit of investigation by making the game worth the candle; for character, judgment, efficiency, and understanding of men develop best in men who work with enthusiasm and intelligence at things that they believe to be worth while.

But there is a second message in the professional demand. For the spirit of investigation accomplishes valuable results only when the investigator is resourceful, accurate, and efficient in mastering facts, and when he has judgment, common sense, and a wide perspective. These qualities depend on the ability to put things in their proper places at the proper times, which ability depends in turn on the perception of intrinsic relationships. The most successful organizer and executive is the one who perceives relationships so clearly that he can build an organization which acts to liberate the creative energy of each in ways that prove most helpful. Hence training in ability to perceive relationships—interrelation—is one essential for the development of resourcefulness, judgment, common sense, perspective, efficiency, and the rest. This is also one essential to the acquisition of knowledge. Therefore in so far as the school work develops the student's ability to perceive relationships, in so far do knowledge and the desired personal traits increase together.

It thus appears that so far as the school work itself goes, the professional demand for upbuilding of character along with increase of knowledge suggests at least two promising lines of educational experiment, namely, motivation and interrelation. The lower schools have long ago recognized the possibilities of these fields of investigation.

In fact, the educational progress of the past century has centred around these two conceptions. Many fruitful experiments and a large literature have gathered about the subject of motivation and the related topics of interest, formal discipline, and transferable training. In like manner much has been accomplished toward interrelation thru efforts that have been made to correlate various subjects, as indicated by the terms commercial-geography, business-arithmetic, household-science, domestic-economy, agricultural-chemistry, soil-physics, and the like.

The organization of curricula proposed in Chapters XIII and XIV is suggested as one practical method of harmonizing the conflicting demands of technical skill and liberal education. It coördinates the results of numerous individual experiments in a consistent program. It recognizes all the essential elements and factors of engineering as well as the educational requirements of motivation and interrelation. It is not a utopian dream, but a summation of the best that has been thought, said, and done in education during the past two centuries. Finally, it embodies the modern conception of the professional engineer, not as a conglomerate of classical scholarship and mechanical skill, but as the creator of machines and the interpreter of their human significance, well qualified to increase the material rewards of human labor and to organize industry for the more intelligent development of men.

APPENDIX

OBJECTIVE TESTS

THE investigations here described were made by Professor Edward L. Thorndike of Columbia University, as an integral part of the study of engineering education. Their bearings on the problems of admission, elimination, and grading have been discussed here and there throughout the report, but especially in Chapters VIII and XI. The types of test used were the following:

MATHEMATICAL ACHIEVEMENT

M_1. *Arithmetical Problems.* The student is allowed thirty minutes to solve five problems requiring arithmetical computation only. The problems are arranged in the order of difficulty and the student is instructed to finish each before passing to the next. The grade is determined by the number of correct answers. The first problem of the series is:

1. A boy was tested with a series of sixteen problems in algebra. He did nothing at all with six of them; he did one correctly except for a mistake in changing signs; he did two with many mistakes in each; he did the others perfectly. He finished the work in one hundred minutes. What was his total credit, supposing that he is given a credit of 8 for each example right, a credit of 3 for each example right except for changing signs, and a penalty of 1 for each minute spent over an hour and a half?

M_2. *Algebraic Problems.* This test is similar to M_1 in that it consists of five problems of graded difficulty, but these require the use of algebraic equations for their solution. The first problem of the series is:

1. Let L stand for the safe load that can be hoisted by a hemp rope. Let C stand for the circumference of a rope. If $L = 100\ C^2$ pounds, how many pounds are a safe load for a hemp rope $2\frac{1}{4}$ inches in circumference?

M_3. *Algebraic Computation.* A series of seven algebraic equations of increasing difficulty, requiring substitution of numerical values and solution for x. The rating is determined by the number of correct answers secured in thirty minutes.

M_4. *Graph Test.* This is a series of five problems of graded difficulty requiring the plotting of a series of points to represent various relations between dollars earned (d) and hours of work (h). The first ($d = 2\,h$) is worked out by way of illustration. The others are:

$$d = \frac{h}{5},\ d = 4 + h,\ d = \frac{6}{h},\ \text{and}\ d = \frac{h^2}{8} + 5 .$$

The score is determined by the number of equations correctly plotted in thirty minutes.

M_5. *Geometrical Proof.* The blank for this test contains a list of fourteen geometrical facts and axioms which are given as proved, and the student is asked to prove five theorems with the use of the data given. As in the other tests the theorems are arranged in the order of increasing difficulty, and the rating is determined by the number correctly demonstrated in half an hour.

Achievement in English

E_1. *Paragraph Reading*. The blank for this test contains three paragraphs, the first very simple, the second more intricate, and the last very complex. Under each is a series of five or six questions as to the meaning of the paragraph. The student may read each paragraph as often as he wishes in order to find answers to the questions. A quick-witted man gets the point from a single reading, while a slower mind has to reread. The score is determined by the number of correct answers written in thirty-six minutes.

E_2. *Range of Vocabulary*. The student is given a sheet on which is printed a series of words, beginning with those in common use and leading up to relatively rare terms. He is asked to write under each word a suitable symbol to indicate whether the word means a flower, an animal, a boy's name, a game, a book, something to do with time, something good to be, or something bad to be. As in the other tests the score is determined by the number of correct answers in a given time.

E_3. *Completion of Sentences*. This is the well-known Ebbinghaus test, consisting of a series of sentences of increasing intricacy, from which key words have been omitted. The student must supply the missing words in such a way as to make sense. The score depends on the number of blanks correctly filled.

E_4. *Verbal Relations*. Twelve minutes is allowed in this test to write the opposite of each of a long list of words, as up—*down*, friend—*enemy*, and so on. The obvious cases at the beginning are followed by more and more difficult cases, like "hiss," "some," "sacred," "if," and "whether."

Achievement in Physics

P_1. *Practical Laboratory Problems*. Each student is given a complete set of the apparatus required to solve eight simple practical problems in physics, such as "connect the electric bell to the dry cell so that it will give a single stroke but will not clatter when the circuit is closed." "With the two ounce weight provided, find the weight of the meter stick." The solution of each is recorded on a suitable blank, from which the score is counted.

P_2. *Described Problems*. This is a series of five ordinary physics problems described in words. They are arranged in the order of difficulty and the student is given twenty-five minutes in which to answer them.

P_3. *Matching Diagrams*. On one half of the blank is printed a series of diagrams and pictures of physical apparatus, each marked with a number. On the other half is a series of statements of physical facts or names of physical phenomena, each of which corresponds to one of the pictures. The student writes at the head of each statement the number of the corresponding picture.

P_4. *Completing Statements*. This is the same type as E_3 except that the sentences in which the missing words are to be supplied are statements from physics texts.

P_5. *Completing Diagrams*. There are eight diagrams representing physical apparatus, but each is faulty because of the omission of several lines. The student must complete the diagrams by drawing in the missing lines.

C. *The Stenquist Construction Test.* Each student receives a box divided into six compartments, in each of which is an assembled mechanical device and the pieces required to construct it. The first contains a simple piece of harness; the second, a snap switch; the third, a door lock; the fourth, an electric bell; the fifth, a clock work; and the sixth, an electric pull socket. The student is given fifty minutes in which to construct the finished models from the loose parts. His score depends on the number he accomplishes successfully in the given time.

The Results of the Tests

In the experiment with thirty-four Columbia College students each student's scores in these tests were combined, and then the students were arranged in their order of merit as determined by this combined score. To test the validity of this order, which was called X, all available information concerning each student was gathered, and the thirty-four were arranged in their order of merit in the following different series:

H. According to high school records in English, mathematics, and physics.
R. According to Regents' examination records in English, mathematics, and physics.
C. According to college records for scholarship in English, mathematics, and chemistry during the freshman year.
B. According to the combined judgment of the students.
T. According to the combined judgment of the dean and teachers.
A. According to age at entrance to college.

The series X was then compared with each of the other series and the Pearson correlation coefficient[1] was computed for each comparison, with the following results:

Correlation of (X) with (H) High School Scholarship	.62
Correlation of (X) with (R) Regents' examinations	.74
Correlation of (X) with (C) Freshman year record	.74
Correlation of (X) with (B) Opinion of classmates	.74
Correlation of (X) with (T) Opinion of teachers	.75

With the age at entrance to college, which is a perfectly objective, altho partial, measure of the student's past ability to get thru the elementary school rapidly or to begin his schooling young, or both, X correlates positively to an extent of .30. This correlation could not be expected to be very close, even if the tests gave a perfect measure of general scholarly power, and is in fact higher for the tests than it is for H, R, C, B, or T, their respective correlations with A being .12, .21, .11, .12, and .19.

If we give each student, as a rating for general scholarly power, or ability with ideas, or intellect in the sense of intellect applied to school tasks, a composite of H, R, C, B, T, A, and X, allowing approximately equal weight to H, R, C, B, and X and half weight to T and A,[2] the rough total score in the tests correlates with this composite (called Ig) to an extent of .84.

[1] If the two series are identical, the coefficient is +1. If one series is the inverse of the other, the coefficient is −1. A coefficient of zero indicates that there is no resemblance whatever between the two series. A coefficient of +.5 indicates a close resemblance, and one of +.9 expresses one of the closest resemblances found in nature — that between the shape of the right and the left hands of the same individual. For detailed directions as to the method of computing these coefficients, cf. Thorndike: *Mental and Social Measurements*, chapter xi. New York, Teachers College, 1913.

[2] T is given only half weight because it is already largely credited under C; A is given half weight because the age at entrance to college is influenced by other causes than ability.

Every one of the tests shows a positive correlation with this Ig, our best obtainable measure of general intellect. The Pearson coefficients are:

M_1.	Arithmetical problems	.625
M_2.	Algebraic problems	.796
M_3.	Algebraic computation	.625
M_4.	Graph test	.614
M_5.	Geometrical proof	.531
E_1.	Paragraph reading	.447
E_2.	Range of vocabulary	.652
E_3.	Completing sentences	.547
E_4.	Giving opposites	.438
P_1.	Laboratory problems	.253
P_2.	Described problems	.531
P_3.	Matching diagrams	.309
P_4.	Completing sentences	.654
P_5.	Completing diagrams	.416
C.	Construction test	.180

Every one of these tests, excepting the construction test, is thus symptomatic of the quality which makes a student enter college young, possess a good record in high school and in the impartial Regents' examinations, do well during freshman year, and be regarded as of high general ability by his classmates and teachers. When all but the last are combined into a single measure they are symptomatic of it in a very high degree. A correlation of .84 is probably closer than that which would be found between the student's average grade in freshman year and his average grade in sophomore year.

The rough total score in the tests which we have called X does not utilize them to the full. In it each test is given a weight in rough proportion to the time devoted to it. The tests, however, differ in their value as symptoms of Ig and should, therefore, have different weights. The probably best weights to attach to each test as a symptom or prophecy of Ig can be determined by the method of partial correlation coefficients, developed by Edgeworth, Pearson, Yule, and Kelley. The calculations, which are necessarily too elaborate to be reported here, were made by Dr. Truman L. Kelley. The numerical values of the coefficients for the various tests were found to be:

M_1.	Arithmetical problems	+.3376
M_2.	Algebraic problems	+.0669
M_3.	Algebraic computation	+.2941
M_4.	Graph test	+.2755
M_5.	Geometrical proof	+.1523
E_1.	Paragraph reading	−.3412
E_2.	Range of vocabulary	−.1429
E_3.	Completing sentences	+.2881
E_4.	Giving opposites	+.0149
P_1.	Laboratory problems	−.0552
P_2.	Described problems	−.0731
P_3.	Matching diagrams	+.0912
P_4.	Completing sentences	+.6639
P_5.	Completing diagrams	−.1910
C.	Construction test	−.0377

The partial correlation coefficients show substantially that a practically perfect prophecy of Ig can be obtained by using the score of the five tests in mathematics, the completion test in English, and the test in completing statements about physics. Combining these seven scores so as to give them relative weights of about 4, 1, 3, 3, 1½, 3, and 7 respectively, we obtain a composite measure (call it ME_3P_4), which correlates with Ig to the extent of .87 (Pearson coefficient, .86; coefficient by the method of squared differences in ranks, .87; coefficient by percentage of unlike-signed pairs, .92).

We can then secure a practically perfect prophecy of Ig by these seven tests alone. They tell us very closely what rating a student would have if we combined his high school marks, Regents' examination marks, marks during freshman year, grades assigned him by his teachers and by his classmates, age at entrance (taken inversely), and score in our fourteen tests (C being excluded). The other three tests in English and the other four tests in physics do almost nothing[1] toward prophesying this Ig, *except in so far as they involve abilities already measured by the completion tests and mathematical tests.*

This does not mean that these tests in English and physics are of no independent value as symptoms of any important abilities in these students. On the contrary, in so far as we may trust the regression equation, they are proved thereby to be of very great value, because they measure abilities which the entire record of school work, examinations, and judgment by teachers and fellow students *fails to measure.*

Just what these other abilities are cannot be stated. Further experimentation and the calculation of other sets of regression equations will be required for that. They certainly include, however, in P_1, P_3, and P_5, some aspects of certain abilities with things rather than abstract elements thereof. These abilities seem likely to be of special importance for future success in the study and practice of engineering. They probably include, in E_1, E_2, and E_4, certain abilities with language which depend on interest in reading, memory of the meaning of single words and phrases, and efficiency in keeping in mind the past context in reading a connected passage.

Negatively, they are abilities which the records of high school and freshman year do not test, and which are other than the abilities for managing symbols and relations tested by the mathematical and completion tests.

Consider now the test in "Construction" or assembling parts to make mechanisms. It shows a positive correlation of .18 with Ig, but this correlation is shown by the investigation of the partial correlation coefficients to be due wholly to elements of ability already fully taken account of by M_1, M_2, M_3, M_4, M_5, E_3, and P_4. The construction test C gives us primarily a measure of abilities not tested by the record of school, entrance examinations, freshman year, and opinions of fellow students and teachers. They are, presumably, *concrete knowledge of mechanisms* and *skill in putting them together.* Here again we have information that the ordinary school records and examinations and the like do not give, and that is probably somewhat prophetic of success in the study and practice of engineering.

On the whole, our tests fall into four groups, each contributing facts of sure, or almost sure, importance. First we have M_1, M_2, M_3, M_4, M_5, E_3, and P_4. When an individual's scores in these are properly weighted and combined, we have a measure (called ME_3P_4) which gives us substantially the same rating as if we combined (as

[1] P3, the test in matching diagrams with the facts or laws which they illustrate, does deserve a small weight (one-seventh as much as the test in completing sentences about physics). The others deserve none.

in Ig) his high school marks for four years in mathematics, English, and physics, his entrance examinations, his marks for freshman year, his rating for general intellect in the minds of his teachers, his rating for general intellect in the minds of his classmates, his age at entrance to college, and his score in our fourteen tests of ability in mathematics, English, and physics. ME_3P_4 thus gives us, within a few days after a boy enters an engineering school, a sufficiently accurate measure of what is commonly regarded as general intellectual ability or promise as a student.

In the second place, we have P_1, P_3, and P_5, the tests with the laboratory problems, matching diagrams, and completing diagrams.[1] Call this combination P_{135}. These measure a mixture of abilities measured by ME_3P_4[2] and other abilities not measured by ME_3P_4 or by Ig. These other abilities seem likely to be prophetic of future success in engineering rather than law, teaching, or business.

In the third place, we have the test in mechanical skill, which has very little in common with the E_1, E_2, E_4 group, and not much more in common with the $M_{12345}E_3P_4$ group, but does have much in common with the P_{135} group, and also much that is peculiar to itself. For the construction test C the correlations are: With the composite of E_1, E_2, and E_4, .166 by the method of squared differences in ranks, .055 by the Spearman foot-rule; with the ME_3P_4 composite, .25 (.247 and .250 by the two methods); with the P_{135} composite, .5 (.61 and .62 by the two methods).

In the fourth place, we have the tests in reading English words and paragraphs and in giving opposites (E_1, E_2, and E_4). This combination, which may be called E_{124}, has a good deal in common with ME_3P_4 (r equals .7), but practically nothing in common with P_{135} or with the tests in mechanical knowledge and skill (r equals .2 for the former and .1 for C of the latter). They have much that is peculiar to themselves.

That each of the first three groups tells us something important about candidates for an engineering education, probably no competent person will doubt. The future careers of students tested as the thirty-four students were tested will give the material for measurements of correlations which will decide their merits beyond dispute.

The fourth group of tests (E_1, E_2, and E_4) give rather specialized information concerning a candidate's mastery of the vernacular, which is useful chiefly as a means of interpreting the results of other tests. If they were left out, we should have nearly as adequate measures of the abilities of direct importance as indications of probable success in the study and practice of engineering as we have from the entire series. We would not, however, be able to tell so well as we could by their aid, whether failure with verbally stated problems was due to lack of scientific and technical ability or to the lack of linguistic ability.

These same tests were given to forty-one freshmen at the Massachusetts Institute of Technology. No adequate measures of Ig (General Intellect) are available, but the value of the tests appears from the following facts: Using the team of seven tests (all five tests in mathematics, and the tests in completing English sentences and completing statements about physics), a boy's score in the tests resembles his average score in the studies of freshman year more closely than does his score in the elaborate series of entrance examinations given by the Institute. The average correlation between the score in these tests and the academic record in either half of the subjects of the freshman year is +.45; the correlation between the median entrance examina-

[1] P_2, the test with the described problems, may belong with this group or in a special class by itself. It probably involves in part the abilities involved by the ME_3P_4 group, those involved by the P_{135} group, and certain special abilities to understand language.

[2] The correlation of P_{135} with ME_3P_4 is .5 (.50 by the method of squared differences in ranks and .56 by the Spearman foot-rule method); the correlation with Ig is also about .5 (.48 and .46 by the two methods just mentioned).

tion mark and the academic record in either half of the subjects of the freshman year is +.87. The correlation between the two halves of the academic record is only +.76.

The tests were given also to forty-one freshmen in the Engineering School of the University of Cincinnati. In this case also there were no such adequate measures of Ig available as was the case with the thirty-four Columbia students. The tests, however, tell how well a boy will do in one half of his freshman studies just as well as his marks in the other half do. That is, using the first three subjects (average of 12 marks), the last four subjects (average of 16 marks), and the record in the selected weighted team of tests (M_1, M_2, M_3, M_4, M_5, and the tests in completing English sentences and completing statements about physics), we find:

The resemblance between the score in the tests and the score in the first 3 subjects is	+.49
The resemblance between the score in the tests and the score in the last 4 subjects is	+.57
The resemblance between the score in the first 3 subjects and the score in the last 4 subjects is	+.49

This team of seven tests also tells how well a boy will be rated in his shopwork for pay nearly as well as does either half of his marks in freshman studies. Neither one, however, corresponds at all closely to this shop rating. The average resemblance of half of the freshman marks to the opinion of the coördinator as to the boy's shopwork for pay during the year is +.22. The resemblance of the selected team of tests is +.14.

Considering the facts from both Cincinnati and the Massachusetts Institute, it appears that the team of seven tests foretells how well a student will do in either half of his freshman year studies about four-fifths as well as does his record in the other half of these studies themselves.

It also appears from a study of the academic records made by the Columbia group in their sophomore year, that these seven tests foretell how well a student will do in the sophomore year at least three-fourths as well as does his entire academic record for the freshman year.

Teachers of engineering will naturally inquire why any technological school should not give these tests to its entering students instead of accepting a high school certificate or a regular college entrance examination. The chief reasons for giving these tests in addition to those of the secondary schools are the following:

1. These tests give relatively much more weight to the ability to deal with "real" situations and problems than ordinary examinations do. In the mathematical work, for example, problems which life could never offer, because to frame the problem one must first know the answer, are rigidly excluded. So also are fantastic and artificial problems invented for disciplinary purposes alone.

2. Ordinary examinations confuse the ability to think and do with the ability to understand verbal descriptions and tell in words what one does think or do. The student who has a good command of language thus gets undue credit. Ability to handle verbally described problems in physics means, for example, ability to understand the words, the necessary knowledge of physical facts and laws, and ability to express one's response in words. A student might be able to repair an electric bell if he saw it, but not be able to tell what the trouble was from a verbal description; or, if he could do the latter, not be able to tell in words how he would repair it. Ability to handle verbal symbols is important, and these tests measure it, but they are designed to measure

also and separately the ability to think with things and diagrams. Three of the five tests in physics demand responses to actual objects or pictures of objects.

3. It has been shown that tests M_1, M_2, M_3, M_4, M_5, E_3, and P_4 together give us a practically sufficient measure of the abilities involved in and tested by ordinary school achievements. P_1, P_3, and P_5 give us something very different. The test for mechanical skill gives us something still different. E_1, E_2, and E_4 give us something still different. If the ordinary examinations were so given as to be as commensurate, objective, scientific, and convenient as these tests, they could be used in place of M_1, M_2, M_3, M_4, M_5, E_3, and P_4; but we should still need to supplement them by P_1, P_3, and P_5, and by the tests in mechanical skill.

4. A high school mark is simply a statement of relative position in that school. The same mark has many values in different high schools; all of these are unknown quantities until they are defined in terms of the actual tasks given during the school course. If John Doe in School A was marked 85 and Richard Roe in School B was marked 75, we do not know how much either knew or could do, or which was the better.

An entrance examination mark has the same defects, altho to a much smaller extent. The examinations in different years may vary in difficulty, and the grades that different examiners would attach to the same set of answers may vary widely. The authorities responsible for these examinations could eliminate the former possibility by proper investigations, and could reduce the latter to a harmless minimum by other investigations. It is not known that they have ever made investigations of either sort, altho the New York Regents' examinations seem to be rather free from both defects.

5. It is unlikely that the average school or entrance examination would show the low constant errors and high correlations between different judges' scores which these tests have. The measurements made by Elliott and others, indeed, lead one to expect a marked inferiority in this respect. Until those responsible for these examinations measure their constant errors and coefficients of reliability, we may fairly assume that they will be inferior to tests devised with especial attention to objectivity.

6. The ordinary examination is a collection of tasks selected largely irrespective of other criteria than that it be a "fair" test, and that it distinguish those below from those above a certain standard for passing. These tests are constructed of steps of increasing difficulty, thereby making possible a fairly definite determination of the degree of difficulty where a student's efforts change from success to failure.

7. In the tests recommended here the plan of constructing the tests, and the details of scoring them, are settled so that the work of arranging for them each year is greatly reduced.

8. The value of all other measurements of an entering class, such as their records in high school or records in the regular college entrance examination, is increased when these tests also are given. They would be worth giving if only as a means of equating to a uniform scale the grades of schools, different years, and the like. The trouble with our present information about students at entrance is not so much that it is intrinsically misleading, as that it requires common denominators to interpret it. The record made in the school of engineering itself is one such denominator. These tests furnish another. Each has its advantages. The two together will enable the officers of schools of engineering to interpret the records sent in by secondary schools and examining boards, and to suggest improvements in the examining machinery by which these records are secured.

To prevent unfair preparation for the tests, and to permit repeated measurements of the same individuals, it is necessary to have many alternative series of each sort of test. These should be so devised that the same person would get approximately the same score for ability in English, ability in mathematics, or ability in physics, no matter by what series of the tests he was tested. If all the alternative forms of each separate test could be equal in difficulty, that would be still better. The plan of these tests permits the selection of such alternates.

The provision of satisfactory alternative series of tests involves much experimentation and statistical work, there being hardly any other satisfactory criterion of "equally difficult" than "such that equal percentages of the same group of students succeed therewith." The group must also be representative, and therefore large.

If the tests described here are found to be as useful in practice as they seem likely to be, state examining boards and institutions interested in knowing what the abilities of their entering students really are should coöperate to provide fifteen or twenty alternative series. That number could, by interchange of elements and by easily arranged devices to detect and penalize heavily any student who had been "crammed" for the specific tests, be made to last indefinitely.

Whatever the merit of these particular tests may be, it is certain that the criteria by which any test should be judged are worth attention. An institution which uses any set of examinations to judge the fitness of entering students should find the coefficients of correlation (1) between each of such tests and another of similar plan, (2) between the score given to each of such tests by one judge and that given by another judge independently, (3) between each of such tests and the Ig or Mg or Eg or whatever ability is supposed to be measured, and (4) between the total score of the team of tests used to decide entrance and the Ig or F (some other measure of demonstrated degree of fitness for the work of the institution). It should not tolerate a system showing a correlation below .9 for the team of tests with Ig or F in the case of pupils from approximately equally good schools. It should use the regression equation or equivalent "cut and fit" methods to find the team of tests which gives a correlation of .9 or more with a minimum cost of time and a maximum amount of intelligibility of units, convenience, and easy extension by alternates and good effect upon the teaching and learning of the lower schools.

Such an evaluation of a set of examinations requires knowledge of the theory and technique of educational measurements and much labor, but there is no other sound way. The merit of a system of entrance examinations is not a matter for divination or faith.

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