FOREWORD

This bulletin presents one of a series of fact-finding studies included in a general investigation concerned with "the objects of engineering education and the fitness of the present-day curriculum" which has been carried out during the years 1924 to 1929 inclusive by the Society for the Promotion of Engineering Education under a grant of funds by the Carnegie Corporation of New York. There is also included considerable material on technical schools giving more intensive forms of training than the usual professional courses in engineering, which was gathered for use in a special investigation in that area.

Both investigations have been conducted under the general direction of the Board of Investigation and Coordination and under the immediate supervision of the Staff, as named elsewhere.

The bulletins are published by the Society through its Board of Investigation and Coordination as the documentation of the investigations, but the responsibility for their contents, for the opinions expressed and for the recommendations made rests in all cases on the authors and editors of the particular material presented. The more general findings and recommendations of the Board, based upon a synthesis of the several studies, are to be published separately.

A COMPARATIVE STUDY OF ENGINEERING EDUCATION IN THE UNITED STATES AND IN EUROPE

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Introduction

Objects and Scope of the Study.—The centenary of technical education in America marks the present decade as a timely occasion for an appraisal of results and a reconsideration of aims and methods. These have been the objects of an extended investigation to which the engineering colleges, the technical schools, the industries, the professional societies of engineers, the United States Bureau of Education and other agencies have contributed a group of important factual and interpretive studies. These unit studies necessarily have dealt with limited aspects of the situation and were made from particular points of view, many of them from within. To round out the data for an adequate appraisal there was an obvious need to survey the situation in a wider perspective and from a more objective viewpoint. The sponsors of the investigation felt that this need could best be met by a comparative study of engineering education in the United States and in a group of leading European countries. As the study progressed it became apparent that the education of engineers as a professional group could not be dealt with effectively apart from the education of the higher and middle ranks of industrial supervisors and technicians. The study was therefore extended to cover both the professional schools of engineering and what are known on the continent of Europe as the "higher technical middle schools." This Bulletin presents both phases of the study. Only incidental reference is made to the training of craftsmen and to pre-industrial training in early adolescence. Secondary education is dealt with in so far as it supplies an essential foundation for higher technical studies. In certain cases a schematic picture of the national scheme of education is included as an aid to orientation.

Terminology.—It is difficult to define the scope of the study and to express its data and findings in terms having a common acceptance. The term "engineering education" is loosely used in America and has no direct equivalent in the more precise terminology of continental Europe. The same term is frequently used in England in a more special sense to denote education for the machine industries. Throughout continental Europe "technical education" is an inclusive term for the training of all ranks of specialists in industrial and building technology, architecture, agriculture, forestry and, in Germany at least, psycho-technics as well. The continental systems may be divided into three quite distinct categories of technical education, commonly called "higher," "middle" and "lower." Our terms "professional" and "vocational" fit the first and last reasonably well, and it is convenient to borrow the term "middle" for the intermediate category, which is less widely recognized in America. It should be pointed out, however, that the French word *professionnel* is practically identical in meaning with our word "vocational." The term "technical education" has been given a legal definition in Great Britain which excludes "teaching the practice of any trade or industry or employment." The term "technology" is commonly used abroad to denote the practical arts of industry rather than the underlying technical sciences.

Acknowledgments.—The data and observations which form the basis of this study were gathered in part by personal visitation in 1925 and 1928 and in part from publications and correspondence in the interim. So far as is known subsequent changes have not altered the principal features of the pictures here presented. The writer wishes to express his gratitude to the public officials, officers of engineering socie-

ties, educators, engineers and industrialists, far too numerous for individual mention, without whose invaluable aid the study could not have been accomplished. He is happy to testify to the cordial interest of the engineers and educators of Europe in the progress of American schools, which has been heightened by the change of America's position from an importer to an exporter of technical products and services.

There is little possibility of direct borrowing from educational systems which have grown out of other economic and cultural conditions. The value of comparative studies, apart from their aid to self-criticism, arises largely from the gain in mutual acquaintance and understanding. Engineering varies in function and practice from nation to nation and the variety of national types is worth preserving as a spur to progress. Its essential genius, however, is universal. As heirs in common to all the arts and sciences engineers have a duty to foster a generous spirit of emulation that may help to lift international competition off a sordid plane. Until recent years America has had the advantage of meeting competion in science and technics largely on her own ground and her own terms, by the simple process of assimilation. Europe has sent us trained men, educational models, professional traditions and the fruits of her research and we have made them our own. We have given in return, but not in equal measure. Henceforth we must balance this account more evenly. While we shall continue to welcome and to assimilate the engineer, the technician and the craftsman of European training, it is plain that we should depend less on this source to fill gaps in our scheme of technical education. The American engineer should be able to meet the world's best in any field on terms of unquestioned equality, both in culture and in technical proficiency.

Technical Education and Economic Well-Being.—These studies will fail of their larger purpose if they do not emphasize the importance of seeing the problem of technical education whole and of bringing some adequate initiative to bear upon it. Experience seems to indicate that it is equally possible to go wrong under a central bureaucracy or by depending entirely on individual and local initiative. France showed remarkable fertility and held undisputed leadership in technical education up to 1850. Then followed forty years of arrested development. The State held an educational monopoly, but took no effective initiative; responsibility was scattered among various bureaus and ministries, each caring for its special needs with little concern for the nation as a whole; the schools were unduly concentrated in Paris; and nearly the whole effort was spent on the training of bureau chiefs and directors of industries, while the subalterns were almost wholly neglected. Local and private enterprise finally came to the rescue, but only after the early supremacy in technical education had been irretrievably lost, with disastrous effect on French industrial development.

Great Britain lost fifty years of her early lead over Germany through ineffectual development of technical education. Before 1880 virtually everything was left to private or local enterprise; few perceived that a specially selected and trained personnel was needed to apply science to industry effectively; nearly a century of effort was concentrated on the incidental teaching of science to workingmen, largely inspired by welfare motives—an admirable thing, in itself, but a wholly inadequate scheme of technical education; meanwhile technical education and research in the universities were almost stifled by lack of support and the backward state of preparatory education.

Nowhere else have technical education and research had so large a share in shaping national destiny as in Germany. Thrown out of the academic institutions through the conservatism of old-school educators, technical education was taken up and fostered by far-seeing statesmen bent on transforming a group of backward agricultural states into a dominant industrial empire. New types of schools, industrial, secondary and professional, had to be created from the ground up. There was an early period of confused effort, but after 1860 it was

increasingly evident that while the states and industries were supplying the greater part of the motive power, the technical professions were guiding the movement out of confusion to clearly visualized goals. Today, the chief guiding agency is the *Deutscher Ausschuss für Technisches Schulwesen*, a central representative committee which brings together the technical professions, industries and schools for effective collaboration with the government ministries in the guidance and support of technical education in all its branches.

In the United States we have done parts of the task well, but other parts we have scarcely done at all and no one has seen the task whole. We began with a broad aim "to apply science to the common purposes of life," but there was an early fixation of technical education in one special form—a professional discipline for engineers. Only this one aspect of technical education has been adequately developed, and in the effort to make it comprehensive there has been an inevitable blurring of aims and compromise of standards. Colleges, professional bodies and industries have not agreed upon specifications. The spirit of technical education is individualistic, without an underlying economic and social program to balance the concern for the personal development of the student. Can this laissez-faire policy be trusted as an adequate guide? Not if the experience of more mature nations under more severe economic pressure may be taken as a criterion. It is plain that we can not look to a central government for a national policy and program in technical education. Our national genius in such matters works through voluntary coordination. The next step is to prepare the way for some central representative agency, such as that in Germany, and to awaken the public to the vital part that an adequate and well-proportioned scheme of technical education and research plays in the general economic well-being.

PART I. THE HISTORICAL DEVELOPMENT OF ENGINEERING EDUCATION

There are significant differences of national thinking as to what an engineer is, what are his functions in the social order and how he may best be trained, which can be understood only in the light of their evolutionary development. The character of institutions, like that of persons, is largely conditioned by heredity and early nurture. Fifty years ago C. O. Thompson, the first president of Rose Polytechnic Institute, observed from his studies of the engineering schools of Europe that there had been little change in their essential features after the first ten years of their existence. From that period on their growth was essentially a maturing rather than a formative process. The present study tends to confirm this general law of development.

National Conceptions of Engineering.—The word *engineer* embodies a Latin root *gen* which denotes highly creative attributes. The direct line of derivation may be traced to *ingenium*—natural capacity, talent, capacity for invention—and is closely linked with the words *genius* and *ingenuity*. The continental languages preserve these root values more faithfully than the English, as in the French *ingénieur*, the Spanish *ingeniero*, the Italian *ingegnere* and the German *ingenieur*. All these languages commonly use some variant of the word *machine* where the English employs the word *engine*. By a trick of etymology the words *engineer* and *engine* have become intimately linked in English speech and thinking, so that an engineer is instinctively thought of as one who builds, applies or operates engines, leaving the connotations of creative ingenuity of the Latin root somewhat obscured. This circumstance has colored British usage to a greater degree than American. In the British sense the term *engineering* is commonly applied to all machine building activities, and the term *engineer* indiscriminately to men engaged in trades, industries and professional services. The engineer is pre-eminently a professional man of special scientific training in continental Europe. British tradition regards the engineer

as a practical builder who has acquired some mastery of the science underlying his art. The method of his scientific formation is incidental, but whatever its extent, he is expected "to go through the mill" of practical apprenticeship. The American conception is less clearly defined, but is intermediate between the British and the continental types.

The Influence of Underlying Traditions.—In origin and historical development British engineering is closely linked with handcraft and continental engineering with formal science. Whereas scientific inquiry, training for practical professions and industrial pursuits were equally cut off during their formative years from the dominant seats of learning in England, the higher schools of the continent became the chief sources of their nurture from the earliest years. These circumstances have directed the main streams of educational activity into widely divergent channels. Motives of individual welfare and traditions which grew up around the pioneers of the industrial revolution led Great Britain to devote her major energies throughout the 19th century to the teaching of science to working men. The need of a specially selected and trained personnel to apply science to industry gained recognition slowly. The chief heritage of the century is a magnificent system of local technical institutions, devoted principally to part-time and evening instruction for industrial employees. The place of technical education and research in the British university system was comparatively small until the last years of the century; since then its development has been greatly accelerated.

The traditional link between engineering and craftsmanship has led Great Britain to preserve in her system of technical education an ideal of "vertical mobility" which is almost wholly lacking in the sharply stratified schemes of the continental countries. France was the first to perceive that the effective application of the technical sciences requires a highly selected and trained personnel and to provide a professional discipline for engineers in schools of the highest rank. France was also first in providing a distinct type of education for industrial supervisors. Germany was conspicuously first to grasp the potentialities of specialized research as the dynamic of technical progress; also the first to provide a universal scheme of vocational education for her youth entering industry in their early years.

Traditional influences have led to an unsymmetrical growth of technical education in America. A century ago the pioneer phase of an effort to promote "the application of science to the common purposes of life" was quickly transmuted into the form of a professional discipline for engineers and assimilated into the newly developing system of university education. Coincident with the railroad there came a demand for engineers versed in the scientific resources of their art. The scattered group of military engineers and self-taught civilians of the earlier period could scarcely be called a professional body. There was nothing to which the English system of pupilage could attach itself and the engineering school arose from simple necessity. The models borrowed from France gave to American engineering education a distinctly professional character and spirit. This early fixation has resulted in a one-sided growth; technical schools have multiplied after the single pattern of the degree-granting college; the systematic training of craftsmen and technicians and of supervisors of industrial production has been largely neglected; we have been tardy in creating an effective group of vocational schools; and the standards of professional "engineering education" have been strained to accommodate forms of training in specialized technology which seem clearly to belong in some other category. European experience indicates that progress to a better rounded system and to higher standards of achievement may be expected only as we define the functions and limit the aims of our schools more precisely and in doing so divide the area of activity among schools of different types and categories, working on different levels of age, previous training and experience, scientific content and specialization, using different educational methods, but all striving to attain the highest degree of excellence.

A. Historical Development, France

The Germinal Period.—The builders of antiquity and the Renaissance were both architects and engineers. The most brilliant examplar of this earlier versatility was probably Leonardo da Vinci. Art and science diverged into separate fields of endeavor so gradually that no time and place can be fixed for the birth of engineering in its modern sense. In all probability the process took place in mediæval France, where the construction of roads, bridges and waterways was a royal concern from the days of Charlemagne. A royal *Corps des Ponts et Chaussées* is known to have existed as early as the 13th century. Charles V (1364–1380) mentions *nos ingénieurs des ponts et chaussées* in a royal ordinance. An episode of the reign of Louis XIV (1642–1715) makes it clear that the engineering profession had begun to develop a consciousness of its own. In his enthusiasm for monumental structures the Grand Monarch commissioned his favorite architect Mansart to build a stone bridge at Moulins on the Allier. Mansart was a master of masonry construction, but he knew nothing of hydraulics and the erosive action of streams. His bridge soon collapsed. The engineers of the period capitalized this setback with a rare sense of publicity and let it be known

> "that they had at their command an art of construction, applicable to great public works, more learned and more varied in its resources, looking to solidity rather than monumental decoration."

Creation of the Ecole des Ponts et Chaussées.—Louis XV (1715–1754) undertook to repair the economic structure of France, shattered by the extravagences of his predecessor. His plans called for the construction of a vast system of national highways. The direction of the work was entrusted to an engineer Perronnet who proved to be a man of exceptional genius. Perronnet may be called the father of modern civil engineering and was certainly the father of engineering education. When summoned to Paris in 1747 to become chief engineer of bridges and highways he was charged

> "with the direction and supervision of surveyors and designers of plans and maps of the roads and highways of the realm and

> of all those who are appointed and nominated to said work; and to instruct the said designers in the sciences and practices needful to fulfilling with competency the different occupations relating to the said bridges and highways."

Perronnet's commission was the germ of the first engineering school. Hitherto engineers had prepared for the exercise of their art by isolated and unorganized studies and the provincial cities where they were often stationed afforded them scarcely any means of professional improvement. The majority had little or no theoretical equipment—imitation and routine were often their only guides. Perronnet found a complete lack of uniformity in standards and practices, as well as in the routines of field notes, reports and estimates. Forced by circumstances to organize a corps of draftsmen bound by common conventions and norms, Perronnet ingeniously transformed this staff into a veritable school of student engineers. In his orders of Dec. 11, 1747 he directed:

> "That these employees will be divided into three classes; the first composed of under-inspectors or under-engineers; the second of employees called *élèves;* and the third of young men of less education who are admitted to work in the office as auxiliaries."
>
> "That the employees of these three classes not otherwise employed will report to the office of Perronnet daily, Sundays and holidays excepted, from eight to noon and from two to eight."
>
> "That exceptional rewards will be given to the three most proficient employees of each class, who are to follow the courses of professors of mathematics and architecture indicated by Perronnet."
>
> "That during the summer, the employees are to be distributed among the principal works in progress, to execute maps and plans."

While the school began to function in 1747 the name *Ecole des Ponts et Chaussées* was not officially bestowed nor the institution legally regularized until 1775. In addition to the external professors provided by Perronnet, he directed the employees of the highest class to act as instructors of their juniors. This scheme of "mutual instruction" continued in force until 1799. Otherwise the school retains most of its original characteristics to this day. It is still an appendage of the official *Corps des Ponts et Chaussées;* the program of studies remains three years in length; the regular students rank as state employees; the professors are in part eminent savants and in part leading engineers of the *Corps;* many of the exercises are actual engineering projects; and the summers are occupied by *stages* at important works in progress. This original pattern has left its mark on all engineering education in France.

The Ecole des Mines.—The mineral industries were largely neglected in France until the middle of the 18th century. When miners or metallurgists were needed they were commonly gotten from Germany. Louis XIV sought to develop the mineral resources of France as a means of revenue to the State. At the suggestion of an ambitious mineralogist Sage, the King authorized the creation of a public and gratuitous school of mineralogy, assaying and metallurgy at the Paris mint. This was in 1778. A royal *Bergakademie* had already been established at Freiberg in Saxony in 1765. These two schools had a dominant place in the early training of the mining engineers of Europe and supplied models to the first mining schools of America. When an official *Corps des Ingénieurs des Mines* was created to foster and regulate the mineral industries of France in 1783 the school at the mint became the *Ecole des Mines* with a rôle analagous to that of the *Ecole des Ponts et Chaussées.* The school passed through many vicissitudes, both internal and external, and the Revolution found it but feebly established. The Convention suppressed it in 1802 in order to create two schools in the mineral basins. The Restoration created an *Ecole des Mineurs* at St. Etienne in 1816 and shortly thereafter restored the *Ecole des Mines* at Paris in the sumptuous precincts of the Hotel Vendome, where it remains today. From that stage on its development was notable. A bureau of tests for mineral substances, the forerunner of industrial research laboratories in engineering schools, was established in 1845.

The *Ecole des Mines* supplied much of the inspiration for the School of Mines at Columbia, opened in 1864, through which it has influenced all the mining schools of America. A British mission which studied technical education on the continent in 1873 reported that it possessed "model laboratories and the most magnificent mineral collection in the world." The *Ecole des Mines* has held consistently to a lofty scientific discipline and has made no effort to simulate industrial operations in its laboratories, holding that the art must be learned where practiced. Practical training has been provided for by placing the students as *stagiares* in the mines during the long vacations.

Ambitious Schemes of the Convention.—At the outbreak of the Revolution the flourishing technical schools for the military and civil functions of the State were threatened with complete disorganization. The students were placed at the disposal of the Minister of War and when their ranks were replenished under the levelling influence of the Convention the new pupils were found to be loyal republicans but otherwise ignorant of the most elementary things of science and mathematics. Lamblardie, Perronnet's successor at *Ponts et Chaussées,* proposed to rectify this situation by creating a great central school for the recruitment of all the technical services of the State, with facilities for a thorough scientific discipline. He confided this idea to Monge, the dominant influence at the school of military engineering, who in turn secured the approval of the Convention. The law of 1794 created an *Ecole des Travaux Publics* to train engineers for all the needs of the army, the public services and private industry. It was a time when men were thinking boldly and easily overlooked elemental limitations. Monge at once began to organize the new institution on an unprecedented scale in the vast premises of the Palais Bourbon. The course was to cover three years and was to comprise both scientific and technical studies. Each "promotion" or annual quota of entering students was to number 400 and to be chosen by competitive examination from the elite of French youth. The school day was to extend from 8 to 2 and from 5 to 8, with the exercises carefully distributed so as to sustain interest and avert fatigue. Ten months of the year were to be given over to teaching, one to examinations and one to vacation. To round out a national scheme of scientific and technical education, the Convention also projected *écoles centrales* in all the provincial

capitals. Neither plan succeeded, yet neither was lost. The *Ecole des Travaux Publics* was replaced after a single year by the *Ecole Polytechnique,* of a more limited character, and the *écoles centrales* proved to be too costly and to lack effective bonds with the elementary education of the times. At a later period, in 1829, the basic ideas were reincorporated in the *Ecole Centrale des Arts et Manufactures,* from which a wide influence radiated throughout Europe and America.

The Ecole Polytechnique.—The idea of a central school for all the technical services of industry and the State was soon abandoned. The specialized schools of application were retained and a preparatory institution "consecrated to a high intellectual and scientific formation" was created as the source of their recruitment. The revolutionary period was one of extraordinary scientific fecundity in France. The new *Ecole Polytechnique* drew to its staff a brilliant group of creative men and at once became the most renowned center of scientific teaching in the world. The names of Lagrange and LaPlace in mathematics, Prony in mechanics, Monge and Hachette in descriptive geometry and stereotomy, Delorme and Baltard in architecture, Fourcroy, Vauquelin, Berthollet, Chaptal and Guyton de Mourveau in chemistry adorn its early annals. Monge was the dominating figure. His enthusiasm for descriptive geometry has left its imprint on all engineering curricula to this day. He brought over from the *Ecole de Génie* the method of admission by *concours,* a severe competitive examination based chiefly on mathematics, which still remains the most distinctive feature of French technical education. The examiners were instructed "to select those who know the best, rather than those who know the most." Napoleon gave the school a military regime in 1804 and it has contributed both directly and through its graduates to the most brilliant chapters in French military history. Since its foundation the *Polytechnique* has been the most eagerly sought after and the most difficult of access of all the schools of France and probably of the world, both because of the prestige of its teaching and its virtual monopoly of access to many of the most coveted state careers. Complaints against this monopoly began to be heard as early as 1796, but have availed little in the face of the unusual esprit de corps of the entrenched alumni. *Ecole Polytechnique* is not strictly a technical school, but it is doubtful if any other institution has had so wide an influence on higher technical education. Strict limitation of numbers, admission by *concours*, a closely prescribed curriculum with a strong mathematical bias, an arduous daily program and a strict regime of work, frequent individual interrogations, ranking by detailed records of daily work as well as examinations, the teaching of the sciences by eminent savants and of technical applications by active practitioners, mark all the French schools of engineering to this day. Many of these features were brought over by Thayer to West Point and by Greene to Rensselaer, whence their influence has spread throughout the United States. French example in creating higher scientific and technical schools entirely distinct from the universities has been followed by other continental countries with few exceptions. The plan of a distinct preparatory stage of scientific studies, followed by a specialized stage of technical application has strongly influenced all the technical schools of middle Europe.

The Conservatoire des Arts et Metiers.—The latter part of the 18th century was remarkable for the number and variety of prototypes of scientific education produced by France. The *Conservatoire* has the unique distinction of combining four of these in a single institution: (1) a museum of applied science, such as we are only now beginning to create in America; (2) a public scientific and technical library; (3) a group of professorial chairs for gratuitous instruction in applied science; and (4) a group of public laboratories for tests and research. The original conception is ascribed to the philosopher Descartes, but the *Conservatoire* itself grew out of a collection gathered by Vaucanson which he kept open to the public during his lifetime and bequeathed to the nation at his death in 1782. The Convention appointed a commission in 1794

> "to inventory and collect in suitable depots the books, instruments and other objects appropriate to public instruction"

and instituted under the present name

> "a public school of applied mechanics, supplied with a rich collection of machines related to all sorts of arts and trades, to serve on one hand for public demonstration and at the same time to give life to the teaching of the professors."

The collection grew rapidly and was installed in 1798 where it is today, in the ancient buildings of the Abbey of St. Martin, which have been repeatedly enlarged and transformed for this purpose. The public engineering lectures were instituted in 1819. The roster of the professors has always included names of the highest eminence. One of the widest known, General Morin, installed here before 1850 what seems certainly to have been the first teaching laboratory of engineering.

The Ecoles d'Arts et Metiers.—France must also be credited with the original type of engineering school of the mechanic arts. The primary conception was due to the Duc de Rochefoucauld who founded an industrial school on his domain at Liancourt in 1788 for the sons of the non-commissioned officers of his regiment of cavalry. The school was nationalized and transferred to Compiegne in 1799. Napoleon visited the school in 1803 and asked some of the older boys what career they planned to follow. The answer of "soldier" displeased the future emperor, in a mood at the moment for peaceful reforms, whereupon he addressed the school thus:

> "The State goes to much expense to train these young men and when their studies are finished, with the exception of the military training, they are of little use to the State. Nearly all become a charge on their families when they ought to be helping them. It will be so no longer. I have just come from a visit to the great factories of the northern provinces and Paris. Everywhere I have found foremen distinguished in their art, with great skill in execution, but almost none who was able to make a drawing, the simplest calculation of a machine, or express his ideas in a sketch or in writing. There is a defect in our industry—I intend to fill it here."

A few days later the official gazette announced:

> "The instruction at Compiegne will have as its purpose to train skilled artisans and heads of shops"

and bestowed the name *Ecole Nationale d'Arts et Metiers.* The school was moved a second time to more commodious

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quarters at Chalons in 1806 and continued on the level of a trade school until 1832, when the age limits of entrance were fixed between 15 and 17 and a *concours* of admission established. The levels of entrance and instruction have been further raised at intervals with the advance of preliminary education, but the early character of a school of mechanic arts for the production side of industry has been consistently maintained. A second school of identical type was established at Angers in 1815, a third at Aix in 1843. Certain politicians sought to suppress the three schools in the budgetary crisis of 1850, but the industrialists came to their defense with such vigor that their existence has never since been threatened. At that time they were the only technical schools in France outside of Paris. Additional schools of *Arts et Metiers* were created at Cluny in 1891, Lille in 1901 and Paris in 1912 and there is a strong demand for still further additions from certain provincial centers. Their present character as schools of industrial production resembles the Worcester Polytechnic Institute in its early years, but practical shop training is even more strongly stressed. In no other country is this type of training so definitely provided for.

Ecole Centrale des Arts et Manufactures.—Napoleon fostered great public enterprises in France and raised the engineering profession to a commanding prestige by his patronage, but it consisted almost wholly of public functionaries. When the Napoleonic era came to an end in 1815 the industrial supremacy of England, gained through private initiative, stood out impressively. France turned to the promotion of private industry, but there was no great center for the training of civilian engineers. The granting of a royal charter to the Institution of Civil Engineers in London in 1828 emphasized the contrast between the strong position of civilian engineers in Great Britain and their weak position in France. These influences led a group of French scientists, Dumas, Ollivier and Peclet, and an engineer Benoit, to join with a public-spirited capitalist Lavallee in creating a private school at Paris in 1829 for the purpose of training civil and mechanical engineers, heads of manufacturing establishments and teachers for technical schools. The principal ideas of the *Ecole des Travaux Publics* and the *écoles centrales* were resurrected and embodied in a program somewhat less abstract than that of *Ecole Polytechnique* to which was added an encyclopædic treatment of industrial technology. The cardinal doctrine of this unspecialized program was stated thus by one of the founders:

> "The science of industry is one and indivisible; every manufacturer or leader of industry must know it in its entirety or remain unequal to its tasks."

Ecole Centrale achieved a brilliant prestige from the start and students were soon drawn to it from a large part of the world. Lavallee at first sustained the school from his private fortune. The fees, amounting to 800 francs per year, yielded a considerable profit. When Lavallee retired in 1857 he refused the offer of a private corporation of 1,000,000 francs for his interest and donated the school to the State, asking only pensions for himself and his colleagues and reserving to the school its financial and educational autonomy. When *Ecole Centrale* was installed in its present quarters in 1884 the accumulated reserves provided $350,000 out of the total outlay of $2,150,000. *Ecole Centrale* exercised a foremost influence in the striking industrial progress of France in the middle portion of the last century. The *Société des Ingénieurs Civils de France* was formed around a nucleus of its graduates in 1848 and has always maintained a filial relation to the school.

As the pioneer school of industrial technology *Ecole Centrale* exercised a formative influence on all engineering education. The Rensselaer curriculum of 1849 * which became an almost universal prototype in America was largely adapted from the course of study at *Centrale:*

* See p. 64.

CURRICULUM OF ECOLE CENTRALE, PARIS, 1850

Year I	Year II	Year III
Descriptive Geometry	Descriptive Geometry	Hydrostatics
Mathematical Analysis and Mechanics	Mechanics	Construction of Machines
Kinematics	Materials of Construction	Steam Engines
Physics (General)	Industrial Physics	Chemical Preparations and Organic Analysis
Chemistry (General)	Analytical Chemistry	Industrial Organic Chemistry
Chemical Laboratory	Chemistry of Industrial Minerals	Mining
Hygiene and Natural History Applied to the Arts	Geology	Architecture
Drawing	Public Works	Furnaces and Foundries
	Manufacture of Iron and Steel	Technology (Mills, oil making, spinning, felting, potteries, etc.)
	Technology (Cordage, textile materials, cutting of wood and stone, etc.)	Railways

The well marked sequences of this program will be observed. Evidently the crowded engineering curriculum is not altogether new. Prof. Greene of Rensselaer is said to have been much impressed in 1849 by the close application of the students with daily attendance from 8:30 to 5 and three or four hours of additional work outside. Under the private regime of the earlier years students were admitted by fairly simple examinations but when the State took over the school in 1857 it instituted a rigorous *concours* of admission similar to that of *Ecole Polytechnique*. Before that time about one-third of the students had been non-French, but the *concours* discouraged the attendance of foreigners which largely shifted for the time to the newly established Federal Polytechnic School at Zurich. This period may be taken to mark the end of the first great creative chapter in the history of higher technical education.

New Sources of Initiative.—The period from 1860 to 1890 was one of arrested development in French technical education, in striking contrast to the vigor of new growth in Germany and America. The State had made technical education its monopoly, but had subordinated it to its bureaucratic system. The higher schools were appendages of various bureaus and ministries, with no source of unified responsibility and initiative. The bureaus looked after their own needs with little concern for those of the country as a whole.

The *grandes écoles* at Paris concerned themselves only with preparing a limited *corps d'élite* of bureau chiefs and directors of industry, while the training of the numerous subalterns was largely neglected. Nothing had been done for the provinces in many decades, other than the creating of a small mining school at St. Etienne in 1816 and the development of the three early *Ecoles d'Arts et Metiers*. By the time local sources of initiative could be created to assume the burden the State had neglected, France had largely lost her early place of international leadership. The first efforts toward decentralization were made by civic bodies; then by the provincial universities in cooperation with regional groups of industries; and, more recently, by various professional and private agencies.

Action by Civic Bodies.—The initiative in creating schools of engineering to aid provincial industries came from civic bodies in the chief industrial centers. The *Ecole Centrale* of Lyons, established in 1857 under the patronage of the Chamber of Commerce, the *Institut Industriel du Nord,* founded in 1872 by the province of Nord and the city of Lille, and the *Ecole d'Ingénieurs* established in 1891 with the cooperation of the city of Marseilles, did much to lessen the gap. These institutions have maintained an intermediate position between the strongly industrial *Ecoles d'Arts et Metiers* and the highly professional *grandes écoles* of Paris.

The University Institutes.—The chief reason, perhaps, for the tardy development of engineering education in the provinces may be found in the state of impotence to which the universities of France were reduced by Napoleon in 1802. For nearly a century they remained mere aggregations of teaching faculties without administrative unity and initiative. The reform of 1896 constituted them as true educational organisms, capable of adapting themselves to a changing rather than a static social order. One of the immediate results was the establishment of a group of *instituts techniques*. The faculties of sciences at Nancy and Grenoble took the leadership in the new movement. With the aid of regional groups of industries they have built up in the last thirty years a flourishing group of technical schools. Their example has been followed at Lyon, Toulouse, Marseille, Lille, Caen and other provincial universities, with the result that the centralization of the earlier period of bureaucracy is rapidly being corrected.

Private Enterprises.—The failure of public initiative left a large area open to private enterprise, especially in Paris. The *grandes écoles* held to a restrictive policy which left many important interests unserved. For example, there was no provision in France before 1891 for the education of the subalterns in the State administration of public works. It occurred to M. Léon Eyrolles, an engineer of the *Corps des Ponts et Chaussées* who had interested himself in the training of his subordinates, that there was a need of a school for this purpose. He began modestly with four pupils and sent the lessons by mail to a few other at a distance from Paris. As the institution met a real need it developed rapidly, both as a resident school and a school of correspondence and gradually extended its field to industrial pursuits as well as State services. Lecture rooms were established in the heart of Paris, where university teachers and engineers in practice could serve as professors, and a school of practice was developed on an extensive tract in the suburb of Arcueil, thus solving the acute problems of space and accessibility. The *Ecole Spéciale des Travaux Publics, du Batiment, et de l'Industrie* has grown to be the largest and most diversified of the technical schools of France, and the one most resembling an American institution. Its work has gradually been raised to a level approximating that of the *grandes écoles* and it surpasses most of them in facilities for practical instruction.

A half dozen other schools, specialized on electrical and mechanical engineering, have grown up on private initiative in Paris in the last twenty years.

The Modern Schools of Specialization.—The latest chapter in the development of French technical education is especially worthy of consideration. It began with the founding of the *Ecole Supérieure d'Electricité* at Paris in 1894 by the *Société Francaise des Electriciens* as an adjunct to its central testing laboratory. The project owes much to the initiative of

Mascart and is probably the first and most important educational institution to be sustained by a professional society of engineers. With the aid of funds subscribed by the electrical industries, the school has recently completed a new and admirable plant. It provides an advanced and specialized program of a single year for men who have already completed a general technical education such as that of *Ecole Centrale*. This type of program, which is known in France as a *cours de perfectionment* or an *année complementaire* is now being adopted in other special schools, conspicuously in the *Ecole Supérieure d'Aeronautique et de Construction Mechanique* which is devoted to the aeronautic and automotive industries and is attended principally by graduates of *Centrale* and *Arts et Metiers*. This school, founded in 1909 on the personal initiative of General Roche, has since been recognized by the State as a school of application for graduates of *Ecole Polytechnique* destined to the State services and has been placed on a semi-public basis. The most recent addition to the graduate schools of specialization is one devoted to foundry practice, in connection with the Paris *Ecole d'Arts et Metiers*.

Retrospect.—It may help us to estimate the profound influence of France in the formative period of engineering education to choose the years 1750, 1800 and 1850 for a series of retrospective views. At the first of these dates France alone had a recognized profession of engineers and a school for their recruitment and training, created within the hands of the profession itself. In 1800 the engineering profession was first emerging in England and could scarcely be said to exist in the United States. There was then no school of applied science in the English-speaking world. Germany was a scattered group of agricultural states, possessing two small mining academies and a feeble school for surveyors and builders. At this period France had two flourishing schools of application for civilian engineers and two others for military functions; she had created the most notable scientific school of the period to assure the recruitment and intellectual culture of a *corps d'élite* of engineers and had engaged her most illustrious scientists in their training; she had created the first great museum of science and engineering; and she had formed in embryo the original group of schools of mechanic arts.

In 1850 Paris was still the world's leading center of engineering education. Great Britain could boast but three struggling centers of engineering instruction, each with a single professorial chair. The United States had but one established school of civil engineering, recently reorganized under French example, and three other schools of applied science in rudimentary stages of development. Germany was in the early stages of her great industrial advance with eight rapidly developing polytechnic schools, three mining academies, and numerous technical schools of lower rank. Switzerland had not yet established her Federal Polytechnic School, but had excellent cantonal schools of middle rank. France had strengthened her position in the half century by creating a renowned school of manufactures, by establishing a group of professorships, notable evening courses and a laboratory of engineering at the Paris museum, and had raised her three schools of mechanic arts to an advanced level.

In 1850 the period of French ascendancy was drawing to its close. The brilliant originality of the revolutionary period had burned itself out. France was entering upon a phase of stable population and internally balanced economic life. There was little population pressure to urge her people toward industrial penetration in outside markets. There was a period of instability in government which checked public initiative and discouraged private enterprise. The disaster of 1871 stripped France of some of her most important mineral and industrial resources and seriously impaired the national optimism. While the French engineering schools maintained unimpaired their high intellectual traditions, they fell behind first the Swiss Polytechnic School and later the rapidly advancing schools of Germany and America in enrollment, material equipment and financial resources. The competitive scheme of admission diverted the rising stream of foreign students first to Switzerland and later to Germany. Being wholly dissociated from the universities and dominated by bureau chiefs and practitioners, the dominant French schools failed in large measure to develop as primary centers of creative effort. Meanwhile the immense growth of research in the hands of professional teachers and investigators in the German *hochschulen* steadily overshadowed the more brilliant but less creative teaching of France. Public initiative under bureaucratic influence failed to foresee and to provide for the developing needs of the country. Local and private initiative finally undertook to close the gaps. In the meantime French technical education passed from its early phase of universal influence into a self-contained phase, effective for France, but of secondary significance beyond her borders.

B. Great Britain

Two Paths of Development.—British technical education has evolved along two divergent paths, quite unlike in their origins and their guiding philosophies. One had its beginnings in a welfare movement for workingmen and the neglected youth of the cities; it aimed to create, in Huxley's phrase, "an educational ladder reaching from the gutter to the university" through part-time and evening instruction for industrial workers. The second path grew out of the pursuit of science in the more progressive institutions of higher learning; its ideals have been those of research rather than immediate welfare, and its goal the creating of a direct link between creative science and practical industry. Both paths have ramified and interconnections have been created in recent years, and there is gradually evolving a fairly balanced and integrated national system.

Traditions Growing out of the Industrial Revolution.—Industry, higher learning, scientific inquiry and training for the professions grew up apart in England and the traditional barriers are not yet wholly obliterated. British industry was the outgrowth of invention and individual enterprise. In its origins it owed little to formal scientific inquiry. Its pioneers were workingmen, trained by apprenticeship and self-taught in rudimentary science. Newcomen was an iron monger, Brindley a mill-wright, Arkwright a barber; Crompton and Hargreaves were weavers, Smeaton and Watt instrument-makers. Telford, a dominating figure in the early years of civil engineering, began work as a stone mason. Stephenson, the father of the locomotive, was an illiterate fireman who learned to read in an evening school in order to gratify his scientific and mechanical curiosity. A deep-rooted tradition grew up around these names. One reads, for example, of "the school of Stephenson." It was assumed that a succession would rise from the ranks of artisans through sheer native ability, helped on by such science as an evening school could teach. The earliest efforts in technical education were prompted by welfare motives. The idea of creating a distinct professional group to specialize on the application of science to industry remained largely alien to much of British thought until the closing decades of the last century, when it was impossible longer to ignore the result of the professionalizing of scientific research and application in Germany and other rival countries.

English science down to 1850 was not only cut off from direct contact with industry, but was equally cut off from the chief centers of learning. The brilliant work of Rayleigh, Davy and Faraday at the Royal Institution casts a deep shadow over the older English universities of the same period. Higher learning was largely in clerical hands and a monopoly of the leisured classes, with little direct connection with the more active professions. Between university and industry there was an open gulf. Oxford and Cambridge preserved the mediæval plan of a congeries of residential colleges, admirably suited to literary culture but ill adapted without a strong central body to scientific inquiry and professional disciplines. The Scottish universities, like those of continental Europe, were organized by faculties rather than colleges and were far in advance of the English universities in scientific effort and professional teaching. The modern universities of England which have shown marked hospitality to pure and applied science and to other professional disciplines in the past half century owe much to Scottish inspiration and example.

Before the advent of the modern professional school the traditional form of training for a profession in England was that of individual pupilage. A group of old laws from the times

of Elizabeth which prescribed an apprenticeship of seven years as the sole mode of entrance to trades and professions was repealed in 1814. This act threw open all but a few callings at the very time when engineering was emerging from the hand-craft stage. The new profession was born under the individualistic star of the industrial revolution. The rise of the industrial system had opened up vast areas of enterprise to middle and lower class groups long excluded from the traditional privileges of rank and title. These newly found opportunities to rise were jealously guarded. Industry was conceived as a private calling and engineering an open profession to be kept as free as possible from state regulation and the old system of social caste.

Pupilage.—The newly formed profession of civil (i.e. civilian) engineers became a self-regulating body rather than one restricted by law. The leading engineers of this early period were themselves products of the old system of indenture and accepted pupilage as the recognized form of professional training. It would not have occurred to them to set up a school for engineers. The Institution of Civil Engineers, founded in 1818 and chartered in 1828, was conceived by its founders to be an agency of mutual education to supplement the limitations of the scheme of pupilage. Only three of its first ten presidents had the advantage of university training and they were of Scottish birth and traditions. An official account of the founding of the Institution states *

> "It was toward the end of the year 1817 that a few gentlemen, then beginning life, impressed by what they themselves felt were the difficulties young men had to contend with in gaining the knowledge requisite for the diversified practice of engineering, resolved to form themselves into a society."

The original by-laws of the Institution explicitly accepted the system of training by pupilage by prescribing that a Member

> "shall have been regularly educated as a Civil Engineer, according to the usual routine of pupilage"

and by enrolling as Graduates those

* *Trans. Inst. C. E.*, Vol. 1 (1836), Introduction.

"who shall not have been less than two years in the office or works of an engineer."

Apprenticeship to a trade commonly began at the age of 14 and continued to the majority. Pupilage was a more individual relationship which began at about 17 after a fair general education of the grammar school type. The principal received a premium of from £100 to £500, according to his reputation and influence, and paid no compensation for any service rendered by the pupil. In return he agreed to instruct the pupil in the arts of design and construction, to provide opportunities for observation and experience and to use his professional influence to give the pupil a favorable start at the end of his period of indenture. Pupilage at its best was a fairly effective initiation to the art, but it had characteristic hazards from which abuses not infrequently arose. The principal was often preoccupied and turned his pupils over to a subordinate, whose teaching was likely to be routine and imitative; there was a temptation to take more pupils than could be given active employment for the sake of profit; the pupil ran the chance of idleness in periods of slack work; and he was tempted to adopt the view that exact science had only an incidental relation to engineering. In many cases the result was little more than an acquired store of empirical standards, formulæ and dimensions. In time the Institution of Civil Engineers recognized the need of some guarantee of adequate scientific attainments and introduced its system of entrance examinations in 1897.

With the growth of large scale industry and its attendant specialization pupilage gradually declined. Vestiges of the premium system remain to the present day. Powerful hands have sought from time to time to give the system a death blow. Prof. Sylvanus Thomson characterized the premium-pupil system as "the worst enemy of technical education" and "the curse of British engineering." In a vigorous editorial in *Engineering* H. W. Maw scored the system as "a plan drawn up with the object of keeping out men who have brains but not money." While pupilage has almost wholly disappeared as a primary form of training, apprenticeship as coordinate with

systematic schooling bids fair to remain a permanent institution. The early schools of engineering made no pretense of displacing pupilage—their training was avowedly auxiliary. The obstacle against which they had to contend was not so much the pupilage system as an attitude of distrust toward scientific methods. The pioneer professors, even men of the caliber of Rankine and Fleeming Jenkyn, were sometimes referred to in mild contempt as "hypothetical engineers."

The Voice of the Profession.—From its foundation in 1818 the Institution of Civil Engineers has exercised a dominant influence on the professional training of engineers. British policy is to leave such matters to the organized profession rather than the law and the professional institution, by virtue of its charter, acts as a quasi-legal body. The first notable British utterance on the education of engineers was the presidential address of Sir John Fowler in 1866, which took fairly advanced ground for the times:

"Taking a boy of fourteen who possesses the requisite qualifications and with a determination on his own and his parents' part that he shall be made an engineer, the period from fourteen to eighteen should be devoted to the special education required by an engineer, during which mathematics, natural philosophy, land surveying and levelling, drawing, chemistry, mineralogy, geology, strength of materials, mechanical motions and the principles of hydraulics should be thoroughly mastered."

"To accomplish these studies and make, in addition, considerable progress in living languages—German and French especially—it will be necessary to sacrifice to some small extent his classical studies and pure mathematics. At eighteen the boy, if duly prepared, may either be placed at once in the office of a Civil Engineer for a period of four or five years' pupilage, or he may be placed in a mechanical workshop, or he may be sent to one of our great universities. . . . If the boy is to go to the university, it is indispensable that all preliminary professional work, such as practical knowledge of mechanics, mechanical drawing, surveying and levelling, should be mastered in advance, because it can scarcely be expected that he will submit to the drudgery of learning them after his return from a three-year university course, then at the age of say twenty-three."

". . . With respect to the special preparation of young men between the ages of fourteen and eighteen several of the largest and best proprietary schools and colleges have special classes and departments for the study of applied sciences, and thence well-prepared pupils are sent out annually to commence their careers with engineers, architects and surveyors, but still the character of this special preparation in theoretical branches is not considered to be quite equal to that of France or Germany. . . . In practical branches we are admittedly superior. Let me be guarded against the possibility of being understood to suggest that this theoretical equality ought to be obtained by any sacrifice whatever of our undoubtedly great practical knowledge; indeed, on the contrary, I think that the attention to the greater opportunities which young engineers in this country enjoy by reason of the number and character of our own public works, than is obtainable in other countries, should be constantly encouraged to the utmost possible extent, and that our superiority as practical engineers should ever be maintained."

Sir John Fowler's address led the Institution to make an extended inquiry and report on *The Education and Status of Civil Engineers in the United Kingdom and in Foreign Countries*, to which further reference is made on page 35. In 1895 Sir Benjamin Baker recalled the above passages in his own presidential address and added:

"Since that time so much has been done that, with the aid of public institutions, training of the kind indicated by Sir John Fowler has been brought within reach of every working man's son. If anything more remains to be said on the subject, it must therefore be of the nature of a warning, that technical education is of little value unless accompanied by the practical experience, sound judgment and bold initiative, which, rather than book knowledge, characterized the famous members of this Institution in the past."

In 1903 the Institution in coöperation with eight other technical and professional societies appointed a consultative committee to consider and report on the whole subject of engineering education under the chairmanship of Sir William White. This committee dealt with the problem in its broadest dimensions, including the coördination of preparatory education, training in offices, workshops and factories, universities and other higher technical institutions. The report was a milestone, in that it placed the sanction of the profession clearly behind the system of higher education in engineering including post-graduate study and research. It was largely influential in fixing the norm of present-day engineering education in Great Britain, especially in universities, and is more fully dealt with in a later section of this study.

The Beginning of Popular Technical Education.—No other country rivals Great Britain in public facilities for the technical education of industrial workers. The origins of the movement supply the key to its ideals and spirit. The oldest school of applied science in the English-speaking world is the present Royal Technical College of Glasgow, which traces its origin to a bequest made in 1796 by John Anderson, leaving all his means

"to the public, for the good of mankind and the improvement of science, in an institution to be denominated Anderson's University"

which was to be open to all classes and to both sexes. Anderson, as Professor of Natural Philosophy in the University of Glasgow, had organized classes in industrial science designed to attract employers and workmen as well as students. James Watt was his instrument maker and it was he who placed a model of Newcomen's engine in Watt's hands for repair, with results which all the world knows. Watt gained the better part of his education through his intimate association with Anderson and the latter was probably influenced by the later achievements of his protege in his plan to create a center for popular scientific education.

An early professor in Anderson's College, Dr. George Birkbeck, organized a special class for *the gratuitous instruction of the operatives of Glasgow in mechanical and chemical philosophy* in the belief that *men should be taught the principles of the arts they practice*. The italicized expressions accurately epitomize the dominant aims and ideals in British technical education for nearly a century. Birkbeck later settled in London and interested himself in a society of workingmen for mutual improvement which became the model for Mechanics Institutes throughout the United Kingdom. The movement flourished with vigor for a time, but had passed into a decline by 1850. The aims in view were sound, but the difficulties were little understood. The general state of elementary education was deplorably low. Secondary education was in private hands and largely limited to the leisured classes. Workmen were unprepared for scientific studies and the methods of imparting education for definite trades were still unknown. The movement was not without permanent fruit, however, for it laid the foundations of a number of important technical colleges, notably at Glasgow, Manchester, Halifax, Huddersfield, Liverpool and Keighley.

The Science and Art Movement.—A fortunate combination of inventive genius, business enterprise, natural resources and isolation from continental wars had given Britain a flying start of half a century in the race for the economic supremacy of Europe. This early success had bred a high sense of industrial superiority and a strong confidence in the sufficiency of practical, trial-and-error methods. The International Exhibition of 1851 at London revealed the fairly startling degree of progress being made by continental rivals, which was at once attributed to their more effective organization of scientific research and education. A cry of alarm arose. It was asserted that Britain "would lose her strength and pride" unless prompt measures were taken to meet the crisis. The Prince Consort, German by birth and training, proposed that the profits of the Exhibition, amounting to £186,000, be increased by a parliamentary grant of £150,000 and used to create agencies "for the instruction of those engaged in the prosecution of arts and manufactures," including a great center of education in applied science at South Kensington.

Hitherto education in all its branches had been regarded in England as a field for private, denominational and local initiative. There was no national system of elementary and secondary schools and the universities were self-governing groups of colleges on independent foundations. Public aid to education took the form of grants in aid of private or local institutions. As there was no national educational authority a Science and Art Department was created under the Board of Trade in 1853 to direct the new effort. However, the force of tradition still prevailed. The plan for a great central institution was set aside and a scheme of money grants was instituted to encourage teachers and schools everywhere in the holding of classes in elementary science and applied art.

The "capitation grants" were based on the number of passes in a group of "science and art examinations." While the result was not wholly good, due to the cramming process which the scheme encouraged, the plan was opportune and served to reanimate the evening classes for workingmen at a time when voluntary effort in the Mechanics Institutes was on the wane. The number of schools receiving grants rose steadily from 9 in 1860 to 2672 in 1895. In the latter year 190,000 students were examined and the grants amounted to £160,000. The Science and Art Department was merged in the newly established Education Department in 1857, but continued to exercise its original function until 1900, when it was replaced by the present Board of Education. At that time the entire scheme of public education, elementary, secondary and technical, was handed over to local education authorities under national inspection and with divided national and local support.

Origin of the London Polytechnics.—An important group of technical schools in London, known as Polytechnics, are the fruit of a welfare movement of interesting origins. In 1865 Mr. Quintin Hogg, quite single-handed, began a work for the religious and social welfare of neglected street boys in London. The growth of this work led him to acquire larger quarters which had formerly been used as a museum and a center for popular lectures on applied science. Hogg retained the original name of the premises, The Polytechnic Institution, and borrowed some of its associations, building up an educational and welfare institution of extraordinary effectiveness on which from first to last he spent over £100,000. A problem arose in the 70's concerning the disposition of the unexpended charitable funds which had accumulated from the endowments of certain parishes in the old City, depopulated through the encroachments of business. The Royal Commission appointed to deal with the problem, headed by Mr. (later Sir) James Bryce, visited Mr. Hogg's Polytechnic and was greatly impressed by its activities. They recommended that the surplus charity funds be used to enlarge the Polytechnic and to build seven others on a similar plan for the education and welfare of the poorer inhabitants of the entire metropolitan area. These institutions have since passed under the direction of the London County Council.

The City and Guilds of London Institute.—The mediæval guilds, organized for the self-government of industry and trade, regulated the training of apprentices until the advent of the factory system broke down the more personal relations of the ancient regime. The guilds or livery companies of London had built up great endowments, principally for educational purposes and have continued to exist as semi-public trusts after their original functions had entirely disappeared. There are still seventy-six of these companies and seven are especially powerful organizations. The Science and Art grants did not include the teaching of technological branches. The Society of Arts instituted a scheme of examinations in technology, as a supplement to the Science and Art examinations, but made no grants in aid. By 1875 the severe limitations of these examinations and grants as a supplement to the remaining vestiges of the apprenticeship system had become a source of serious concern. A tide of agitation arose for a more effective scheme of technical education. Huxley and Sylvanus Thomson took up the issue, protesting against taxing the rate-payers as long as the livery companies held vast educational endowments. The movement led to the organization of The City and Guilds of London Institute which began work in 1879 under a four-fold scheme of activity:

1. A system of technological examinations and grants-in-aid to supplement the work of the Science and Art Department. (Examinations and certificates are still maintained on a wide scale, but grants were discontinued in 1891.)

2. The establishment and maintenance of a technical school at Finsbury and a school of applied art at South Kensington.

3. Grants in aid of engineering education at University College and King's College, London.

4. The establishment at South Kensington of a central institution to give technical education of the most advanced character, for the training of engineers, industrial managers and teachers. (The City and Guilds Engineering College, now a constituent part of the Imperial College of Science and Technology.)

This act has been acclaimed as the most forward-looking of any in the entire history of British technical education. It broke down the old theory of private responsibility and placed it on a quasi-public body. It extended recognition and financial aid to the teaching of technology as well as science. It prepared the way for the creation of the great central scientific and technical institution foreseen thirty years before by the Prince Consort. The total of the donations and expenditures of the Institute up to the end of 1924 exceeded the sum of £1,200,000.

The school at Finsbury began its work in 1879. It was directed by able men, Sir Philip Magnus and Prof. Sylvanus Thomson among them, and exercised a formative influence on local technical institutions throughout Great Britain. Day classes were provided for persons of both sexes who wished to prepare for intermediate posts in industry or for entrance to the central school at South Kensington. Evening classes were organized for apprentices, artisans and foremen in five divisions: mechanical engineering, electrical engineering, technical chemistry, applied art and trade subjects. At the outbreak of the recent war financial limitations led the City and Guilds Institute to transfer the institution to the London County Council which maintained it until 1926 when it was closed on the plea of post-war economy.

Origins of the Local Technical Institutions.—A serious trade depression extending from 1884 to 1886 rekindled the fear of foreign competition. Again there was a widespread alarm over the inadequacy of British technical education. A Royal Commission of Inquiry prepared the way for a series of parliamentary acts which empowered the County Councils to create and maintain local technical schools and to appoint boards of "local educational authorities" to direct them. The Act of 1889 gave the term *technical education* a legal interpretation:

> "The expression *technical education* shall mean instruction in the principles of science and art applicable to industries and in the application of special branches of science and art to specific industries or employments. It shall not include teaching the practice of any trade or industry or employment."

The Act of 1890 handed over to the local authorities large sums from the customs and excise duties, known as "whisky money" to aid in the founding and maintenance of technical schools. Many old institutions, the outgrowth of mechanics institutes, science and art classes and aided classes in technology, were thereupon taken over by the local authorities. New institutions sprang up rapidly.

While ample funds were now available, there were still lions in the way. Elementary education had been made compulsory, under public regulation, as late as 1876; the school leaving age for the great majority was about 12 or 13; there was no national system of secondary education and a wide gap existed between popular and higher education; and the funds provided by the technical education acts could not be used to round out deficiencies on the literary side of education. The inevitable result was that most of the activity resulting from the acts gravitated to the level of junior or post-primary technical day schools and evening technical classes of junior or secondary grade. A few of the cities, notably Glasgow and Manchester, built up technical colleges which offered day instruction of the university standard as well as work of a more popular grade and which later became affiliated with neighboring universities as faculties of technology.

The Education Act of 1900 established a national Board of Education and handed over to the local authorities the operation of the entire scheme of public education. Since that time secondary education of an academic type has been greatly extended, leaving to the local technical schools the field of post-primary day education along industrial lines and the field of part-time and evening instruction in applied science, art and technology. Through the Act of 1900 fifty years of effort to create a system of popular technical education came to larger fruition in a comprehensive system of national education. The local technical institutions, now numbering more than two hundred in England and Wales, as well as twenty-one in Scotland, constitute the apex of the local scheme of

education. They are certainly the most distinctive British contribution to education in applied science. The historical genius of these schools must be sought in a welfare motive. Huxley once described the British ideal of technical education in the apt phrase "capacity-catching machinery." On another occasion he spoke of the task of "building an educational ladder reaching from the gutter to the university, up which any child in the three kingdoms may climb as far as his capacity will take him." In no other group of institutions in this ideal more closely realized.

The Growth of University Engineering Schools.—The preceding sections are barely able to suggest how long and persistently Great Britain pursued the ideal of individual welfare in technical education and sought to bring to industry the fertilizing power of science through the "education of hands rather than heads." It also suggests the traditional distinction between "technical" and "university" education—the one local and intimately associated with regional industries and the other non-local and closely related to scientific research. Between the two there is also the gap of matriculation and the degree but this has been appreciably lessened by the creation of a system of "national certificates" and "national diplomas" for non-degree courses.

The effort to create a system of higher engineering education in university colleges faced adverse odds from the beginnings in 1840 down to the close of the last century. The professional body jealously guarded the old traditions of practical training. Many of its leaders distrusted a less heroic discipline than that of "work all day, study all night" on which they themselves had been raised. Industrialists not infrequently viewed science with mild contempt as something remote and abstract. The premise that leaders are born and not made led to the inference that they would fight their way to the top with little aid and encouragement. The underpinning essential to professional schools of engineering was largely lacking. Nearly fifty years were lost through delay in creating a national system of secondary education with an efficient modern side. Oxford and Cambridge followed rather than led; physical science had scarcely a foothold in their precincts before 1850 and there was no provision for experimental study and research before 1870. The Scottish universities were of great service to applied science, as the names of Rankine, Jenkyn and Kelvin will suggest. The modern universities of England, which grew out of an older group of university colleges and have probably done more than any other agency to destroy the monopoly of classical learning in English education, date their history from 1880 and their rapid development from 1900. At the latter date there were only 345 third year and 52 fourth year students of engineering in the whole of Great Britain and many of them had entered at the age of 15. Since 1900 the gap which long separated England from her neighbors, in matters of higher education, has been nearly if not wholly closed.

The first of the university colleges was established under the name of the "University of London" in 1827. It was a proprietary institution without a charter. Its fees were low and no religious restrictions were imposed, the aim being to make a high standard of education available to students cut off from the older universities. There was a storm of criticism against this "godless institution" and a rival known as King's College was soon erected under Church auspices. These two colleges early became centers of active scientific inquiry, and were the first to introduce the teaching of engineering. Both established chairs of civil engineering in or about 1840 and there are evidences of still earlier teaching under other names. The chair of civil engineering at the University of Glasgow also dates from 1840. A Royal College of Chemistry was created in London on a private foundation in 1845. In response to numerous memorials from the mining industry a Government School of Mines was established in London under the Board of Trade in 1851 and was installed in the Jermyn Street Museum. Two years later the School of Mines and the College of Chemistry were merged under the direction of

the newly created Science and Art Department. The University of Edinburgh established its chair of civil engineering in 1865.

Mention has been made on page 28 of the inquiry into the education and status of civil engineers in 1868 and 1869. This survey revealed how far continental Europe and the United States had outstripped Great Britain in the development of professional schools. Britain could show in all but seven centers of engineering instruction, all small and struggling, five having but a single teacher for all the engineering branches. There were meagre laboratories for the physical sciences and no engineering laboratories of any sort. University College, London, probably the first institution to introduce a complete engineering course and a recognized leader in 1870, may be taken as an example of the period. There was a single professor of engineering, entrance was permitted at the age of 15, there was no entrance examination and the enrollment numbered around fifty; the tuition fees for the three years' course amounted to more than £125; there was no engineering laboratory; and the curriculum of the period was as shown below;

University College Curriculum of 1870

	Hours per Week		
	Year I	Year II	Year III
Arithmetic and pure mathematics	6	6	3
Applied mathematics	3		
Applied mechanics		3	3
Physics	3	3	
Physics laboratory			6
Chemistry	5		
Chemistry laboratory		4	
Civil engineering		3	
Mechanical engineering			3
Machine drawing and design	6	6	6 or 4
Surveying		1	
Geology	2		

These simple annals represent forty years of struggle against odds of indifference and neglect, yet the period was illumined by some notable personalities—Vignoles at University College, Wheatstone at King's, Huxley and Playfair at the School of Mines, Rankine at Glasgow and the many-sided Fleeming Jenkyn at Edinburgh.

The Turn of the Tide.—From 1880 on the fortunes of the university schools of engineering were in the ascendant. The City and Guilds of London Institute was the first public agency to take engineering education under its fostering care. It assisted University and King's colleges with money grants and established under its own auspices the City and Guilds Engineering College at South Kensington, adjoining the Royal School of Mines and the Royal College of Science. With the opening of City and Guilds College in 1884 England possessed for the first time an ensemble for teaching and research in technical science comparable to the many great schools of continental Europe and America. The Prince Consort's vision of 1851 did not reach its full consummation until 1907, when the three schools at South Kensington were federated into the Imperial College of Science and Technology, often referred to at that period as the British Charlottenburg. The tribute to the famous institution at Berlin is well deserved, for it is plain that the force which stirred England to action was German example and competition.

A second event of 1880 to mark the turn of the tide was the chartering of the first of the "modern" or "urban" English universities, Victoria at Manchester. This was an outgrowth of Owens College, established in 1851 to teach

> "such branches of learning and science as were then and might thereafter usually be taught in English universities."

Owens was a maker of precedents for the university colleges which arose in the chief provincial cities and later were erected into universities. These institutions owe more to the example of the Scottish universities than to Oxford and Cambridge. They were organized by faculties and departments rather than residential colleges and welcomed the physical and technical sciences from their earliest years. Their service to engineering education, in giving it the prestige of a place in the university system, can scarcely be overestimated.

The Period of Rapid Growth.—The example of Victoria ushered in a period of university expansion of almost unparalleled rapidity which swept engineering education forward with the tide. University College, Liverpool, was incorporated into Victoria University in 1884, followed three years later by Yorkshire College of Leeds. Mason College, Birmingham, founded in 1880, was chartered as the University of Birmingham in 1900 and came forward rapidly as one of the chief university centers of engineering activity. Victoria was separated into three distinct universities at Manchester, Liverpool and Leeds in 1903 and 1904. Firth College at Sheffield, founded in 1879, became a university college in 1897 and the chief nucleus of the University of Sheffield which was chartered in 1905. Sheffield has long been prominent as a center for the teaching of ferrous metallurgy. The University of London was created by federating University and King's colleges in 1836. In 1850 a new charter was given and candidates were admitted to degrees from affiliated colleges in various parts of the country. In 1900 it was reconstituted in its modern form as a federal group of teaching institutions with engineering departments at University College, King's College, East London College and the Imperial College of Science and Technology. The University of London continues to act as a central examining and degree-granting agency for a considerable group of other university colleges, polytechnics and local institutions. Bristol incorporated the Merchant Venturers' College (1885) as its faculty of engineering when it received a university charter in 1909. Reading became the latest accession to the university group in 1926. University colleges at Nottingham (1881), Southampton (1902), Exeter (1922) and of still more recent origin at Leicester and Hull, all pressing to the goal of university status, indicate the momentum of the present effort to make higher education in both its liberal and professional aspects as widely accessible in England as it has long been in Scotland, France, Germany and America. In the winning of this fight the early schools of engineering had no inconsiderable share.

The Older Universities.—The Scottish universities have traditionally preserved the union of liberal and professional education and were among the first to provide for the teaching of engineering. Durham instituted the teaching of civil and mining engineering in 1837, but the movement was short lived and it was not until 1871 that an enduring work was begun at Armstrong College at Newcastle, under the joint auspices of the University and the North of England Institute of Mining and Mechanical Engineers. Cambridge began to turn a friendly eye toward mechanical science soon after the physical sciences had been firmly established under Clerk Maxwell. Under the leadership of Prof. James Stuart workshops were installed and lectures on applied mechanics instituted in the 80's. Sir Alfred Ewing, Stuart's successor, was instrumental in placing engineering on a substantial foundation at Cambridge through the creation of an honours tripos in mechanical science in 1890 and the installation of an extensive laboratory. From that time on engineering gained rapidly at Cambridge; the enrollment had risen to 250 by 1913 and has since nearly doubled, making it the largest of the university schools of technical science. Oxford came into the field late and on a very modest scale. A chair of engineering science was established in 1909 and a laboratory erected in 1913, since which time Oxford has enrolled an average of about thirty students of engineering.

The Higher Technical Institutions.—The forces which were making for university expansion were at the same time transforming a group of local technical institutions into higher schools of engineering. The Glasgow and West of Scotland Technical College was created out of Anderson's College and two other institutions in 1886; nine years later it occupied a magnificent plant erected by popular subscription; in 1912 the King bestowed its present name, the Royal Technical

College; and a year later it became affiliated with the University of Glasgow as a faculty of technology. Heriot-Watt College worked out a similar relationship to the University of Edinburgh and Robert Gordon College to the University of Aberdeen. Under the technical education acts of the late 80's the city of Manchester developed an old school of secondary rank which traced its origin to the Mechanics Institution of 1824 into a great Municipal College of Technology. The city sent a mission of inquiry to the chief continental centers of technical education and in 1902 erected one of the most extensive educational plants in Great Britain. Three years later the College became affiliated with Victoria University as a faculty of technology, at the same time retaining its functions as a local technical institution. These instances were part of a widespread movement through which the educational ladder from the gutter to the university, of which Huxley spoke inspiredly in the 70's, has become at last a reality.

Dominant Influences in the Last Fifty Years.—In the brief scope of this study it is not possible to unravel fully the complex forces at work in the transition of the last fifty years. Only a few outstanding strands can be traced. The boldest of these was the persistent fear of industrial competition from abroad. From 1850 on every wave of popular concern over technical education can be identified with a trade depression or some disquieting challenge from French, German or American industry to Britain's traditional faith in her inventive genius, practical skill and business sagacity. This attitude was never more active than it is to-day. The war and the post-war depression have created a new attitude toward science. Stanley Baldwin has struck the keynote of the moment in his declaration "the future rests with the nation which is most successful in harnessing science to industry."

The story of British technical education is one of movements, usually groping their way by trial and error, rather than one of dominant leadership by men and institutions as in France and Germany. There is one individual, at least, whose leadership deserves a special tribute—Dr. H. W. Maw, senior editor of *Engineering* from 1870 to 1924, whose pen was seldom silent on the problems of engineering education. Beginning with the first issue that came from his desk Maw campaigned incessantly for a sound educational policy, analyzing the special problems of technical education at a time when these were little understood, urging the need of a sound underpinning of elementary and secondary education, pointing to the inadequacy of "broadcasting elementary scientific information" through the Science and Art classes, holding up as a challenge the best that was being done in other countries, and reiterating constantly the necessity for creating a few engineering schools of the highest scientific rank. Only one brief fragment can be given to illustrate the force of Maw's editorial style:

> "We are spending more than a million a year out of the rates and taxes on technical training and very much of it is wasted. The teaching of young mechanics and others the elements of science and handcraft, though not without value, is of little advantage in meeting the competition of Germany and America. It is equivalent to teaching private soldiers the principles of strategy."

Maw did his work through his leading editorials, of which he devoted an average of more than five a year for over fifteen year to educational subjects, the maximum rising to ten in 1897—a record unapproached in the history of engineering journalism.

Great influence was wielded by a series of educational missions abroad. Once awakened from her complacency, England sought to know and use the best that had been created in other lands. One of the most interesting of these missions was sent to America in 1902 at the personal expense of Mr. A. Mosely. The mission was prompted by Mr. Mosely's observation of the work of a group of American mining engineers in South Africa to whose technical skill, resourcefulness and business sagacity "the primary success and subsequent prosperity of these mining centers was due." The mission was charged to consider:

- The development of individuality in primary schools;
- The social and intellectual effects of the wide distribution of secondary education; and
- The effect of specific instruction given (*a*) in business methods and (*b*) in applied science.

The report of the mission emphasized particularly the greater practicality and accessibility of higher education in America.

The breaking of the monopoly of secondary and university education long held by the leisured classes was profoundly important to engineering education. The contrasting records of England and Germany reveal in a striking way the indispensable role of a system of secondary education which is accessible to all social classes and offers equal resources for scientific and literary culture in the upbuilding of higher engineering education. As long as such a system was lacking in England, the university schools of engineering struggled against hopeless odds; since its creation, their development has been notable, but the delay cost nearly fifty years.

A final lesson from the record of Britain stands out with special boldness—there is nothing more perilous to industry than the dissociation of technical education from high and disinterested scientific research, a defect long tolerated but now happily corrected. While the universities and local technical schools have not become wholly differentiated in function and probably should not be, in principle and increasingly in practice the former tend to unite technical education with fundamental research and the latter with the immediate needs of industry through the medium of part-time instruction. An effective balance between the two is still incompletely worked out, but the situation is rich in its possibilities.

C. The German States

Technical Education and Statecraft.—The resurgence of the German states after the defeat and dismemberment of the Napoleonic era was the historical miracle of the 19th century. Awakening fully for the first time since the middle ages, Germany threw off her mood of futile romanticism and turned toward the future with a resolute realism. This break with the past gave a great impetus to new forms of education and scientific endeavor. Far-seeing statesmen began deliberately to rebuild the old agricultural states into the modern industrial empire. There is probably no other region, great or small, in which technical education and research have had so large a share in shaping national destiny. Witness the testimony of the eminent French sociologist, Charles Gide:

> "It is technical education, patiently pursued, conscientiously assimilated, which has been for Germany an arm more powerful than the spirit of enterprise of the English and the artistic feeling of the French. She owes to it her admirable commercial and industrial advance."

The initial impetus came largely from state sources early in the last century. The states had important monopolies and industrial interests of their own—forests, mines, communications and manufactures of military material—and stood in need of trained technicians for their development and officers for their administration. The industrial supremacy of Great Britain was a source of bitterness. Manufactures which had been set up under the "continental system" of Napoleon were not standing up in competition with England and Belgium. Industry was everywhere in low esteem among the higher classes, state employment everywhere desired. The national heritage of natural resources was relatively meagre. Capital for the expansion of industry was scarce; as the states could not create it, they turned to the creation of skill and intelligence as the remedy for the economic ills of the moment and the guarantee of future security.

The Roots of Technical Education.—The transition from the traditional system of apprenticeship to modern forms of technical education began under difficulties in Germany, but was ultimately carried through with unexampled thoroughness. Late in the 18th century there were tentative efforts to give technical education a place in the universities, by introducing the teaching of chemical and mechanical technology dressed up in the Latin name "cameralia." In 1773 Prof. Eberhard lectured on applied mathematics at Halle, but his

efforts to secure a recognized place in the curriculum for this and kindred subjects met with refusal. Heidelberg and Göttingen also made tentative beginnings in technical branches of science at about the same period.

As soon as the issue was clearly defined, however, the ruling academic party refused to admit the technical sciences, regarding them as wholly alien to their cherished ideals and traditions of disinterested learning. The result was a sharp cleavage between academic and technical education. The gymnasium and the university stood together as a closed system and an entire group of new institutions had to be built up completely from the ground. The early technical schools had no choice but to superpose their programs on the *volkschulen* of the common people and were therefore scarcely more than trade schools. To create a group of technical schools equal in all respects to the universities was the work of a century and would have been impossible without the creation of a modern type of secondary school as a counterpart to the classical gymnasium. The rise of the *technische hochschulen* and the *oberrealschulen* was essentially a single movement. The two made common cause and achieved a common triumph. No historical situation shows more clearly the intimate dependence of higher technical education on a sound and sympathetic scheme of secondary education, unless it is the retardation of half a century which resulted in Great Britain from the lack of such an underpinning.

The First Technical Schools.—Having been cast out by the academic powers that were, technical education was nurtured in its infancy by officers of state. Prince Xaver of Saxony founded a royal *bergakademie* for the teaching of mining and metallurgy at Freiberg in 1765. Intended primarily for the training of state mining functionaries, the *bergakademie* remained a small and provincial institution for a long period. Its indirect influence was great. It deviated from the universities in combining theoretical teaching with practical work in laboratories, inspection of mine working, journeys of observation and actual work in technical callings, procedures later adopted and greatly developed in the *technische hochschulen*. The principle of *lehr- und lern-freiheit*—the freedom of the teacher to teach and that of the student to study what he chooses—which is so jealously guarded in all higher institutions in Germany was here observed from the beginning. It was introduced into the universities by von Humboldt, who became acquainted with it as a student at Freiberg. Toward the middle of the last century Freiberg gained an international renown and was largely attended by foreigners.

In 1799 Frederick William III of Prussia established a royal *bauakademie* at Berlin for

> "the theoretical and practical training of skillful land surveyors, civil and hydraulic engineers, especially for the royal states, to which training foreigners also are admitted, in so far as this can be done without prejudice to native pupils."

While the aims of the *bauakademie* were ambitious it was actually a school of elementary character. Students were permitted to enter at the age of 14 with only a common school education. There was a course of study for surveyors of three semesters and one for constructors of five. It is worthy of note that the traditional hospitality to foreign students which has contributed so much to the renown of the German engineering schools was foreshadowed in the original plan of the *bauakademie*.

The states of the old Austrian empire made beginnings in technical education at about the same period. In 1801 the state of Bohemia commissioned Count von Gerstner to draw up a plan for a polytechnic school in Prague, under the influence of French example. The school was opened in 1806; like the building school at Berlin it admitted students at the age of 14 with common arithmetical preparation. The Polytechnic Institute of Vienna, established in 1815, had a preparatory section or *realschule* of two years which could be entered at the age of 13 and a higher technical section with a three-year course. The later development of these schools has closely paralleled that of the schools in Germany proper.

The Rise of the Technical Universities.—The rise of a group of institutions from the level of trade schools on the

borderline of elementary education to a powerful and homogeneous group of universities, together with the inseparable upbuilding of modern secondary schools, has been acclaimed as the greatest achievement in educational organization in the Germany of the 19th century. Three distinct periods may be discerned in this evolution; (1) a trade school period marked a diversity of origins and types and extending from 1799 to 1835; (2) a period of transition from trade schools of narrow purposes to polytechnics of wide scope and professional rank, extending to 1875; and (3) a period of development on a university plane extending to the present, but notably marked by the official bestowal of full university prerogatives in 1900. To trace the evolution of each of the present eleven technical universities would be beyond our present purposes. The story may be epitomized by outlining the growth of the two which probably had the largest influence in shaping the common norm of today. Karlsruhe had the greater renown and formative influence in the two earlier periods, but Charlottenburg came to have a commanding position in the later stage, after Berlin became the seat of imperial influence.

Karlsruhe.—Agitation in the state of Baden for the establishment of a polytechnic school began to gather force as early as 1808. The leader of the movement was Nebenius, liberal statesman and economist, who re-drafted the constitution of Baden, built its railways, revised its scheme of taxation, reorganized its education and was largely influential in creating the customs union. Nebenius was familiar with the great technical schools of Paris and sought to create in Baden a school of more general scope which would train leaders for industry as well as officials for the state services. The polytechnic school at Karlsruhe, the first of its kind in Germany, was created in 1825 by combining an older state school of civil construction with a private industrial school.

It was not clearly perceived at that time that schools of different types were needed for the training of artisans and directors. Instead the effort was made to make the same program meet both needs by merely varying the length of the course of studies. Nebenius soon grasped the need of a separation. He urged the creation of distinct schools, one aiming at much skill with a modicum of scientific knowledge (*fachschule*) and the other at a high scientific discipline with less dexterity (*hochschule*). In 1833 Nebenius reorganized Karlsruhe on the latter pattern, which he felt must precede the former in its development. This point marks the cleavage between the higher, middle and lower technical schools of Germany. From 1833 on Karlsruhe was essentially a professional school with an internal organization resembling the universities. The faculty was a self-governing body, choosing its own rector annually. The Prussian schools did not attain a like degree of autonomy until near the middle of the century.

The curriculum of Karlsruhe in 1833 was advanced for so early a period. There was a preparatory realschule of two years which could be entered at the age of 13; then followed a general scientific section of two years on the lines of the *Ecole Polytechnique* of Paris; and there was a final stage of application with separate sections for architects (6 semesters), for civil engineers (4 semesters) and foresters (4 semesters). A later reorganization in 1863 foreshadowed in some detail the present norm of a technical university. The *realschule* was dropped and admission was based on a *realschule* certificate, with a minimum age of 17; the general scientific section of two years was retained; and the professional sections were enlarged to include architecture, civil engineering, building construction, chemistry, mechanical engineering, forestry, commerce and postal services. The revised curricula began and ended on much the same levels as those of the better engineering schools in America at the present. The title of *hochschule*, which serves as an inclusive term for all institutions of university rank and character in Germany, was not adopted until 1885.

Charlottenburg.—The original nucleus of the present technical university at Charlottenburg was the *bauakademie* at Berlin, founded in 1799. The first definite movement in

Prussia to promote the growth of manufactures through technical education appears to have been made on the initiative of the eminent state councillor Beuth, who established in 1822 at Berlin a *technische schule* which soon developed into a complementary institution to the older *bauakademie*. It was at first a simple trade school which pupils might enter direct from the elementary school at the age of 14. The rise of its standards was reflected in successive changes of name to *gewerbe-institut* in 1827 and *gewerbe-akademie* in 1866. Beuth reorganized both the *bauakademie* and the *gewerbe-institut* in 1849, raising the minimum age of admission to 17 with the additional requirement of a *realschule* certificate. The courses of study were placed on a thorough and practical basis and given an engineering character. It was at this time that the principle of *lehr- und lern-freiheit* was first introduced into the polytechnic schools. The course of study at the *bauakademie* of 1850 consisted of three years in common for civil engineers and architects, followed by one year of specialization. The curriculum of the *gewerbe-institut* covered three years and there was an additional requirement of a year of industrial experience. The instruction in the first two years was devoted to higher mathematics, physics, chemistry, drawing, mechanics, mechanism, metallurgy and machine construction; while the final year was divided into separate sections for chemistry and mechanical engineering, in order to give the students a more detailed introduction to industrial applications.

The victory over France in 1871 with its attendant conquest of Alsace-Lorraine, the unification of the German Empire and the vigorous economic policies of Bismarck gave an immense impetus to the industrial expansion of Prussia which was quickly reflected in the growth of the technical schools. As the two schools in Berlin had begun to overlap appreciably, the State combined them into a polytechnic school in 1876 on the lines of Karlsruhe and the Swiss Polytechnic School at Zurich. Three years later the title and status of *hochschule* was bestowed, making the institution a university in all except name and the right to award degrees. Prussia now set itself to house the united institution, the largest of its type in Germany, on a scale of unexampled magnificence. A group of buildings was erected in the suburb of Charlottenburg at an outlay of $2,500,000 and was dedicated in 1884 by the Emperor William I in person, with the most impressive signs of imperial favor. This event reacted strongly on the prestige of technical education and placed Charlottenburg in a position of leadership. At the celebration of the centennial of the old *bauakademie* in 1899 an even more significant event occurred, the official recognition by the Emperor William II of the equality of modern and traditional forms of education and the bestowal upon the *hochschule* at Charlottenburg of the formal prerogatives of a university, including the right to award the degrees of *diplom-ingenieur, doktor-ingenieur* and *doktor honoris causa*. The King of Wurttemburg at Stuttgart quickly followed the imperial example and within a short period all the nine existing *technische hochschulen* were invested with similar rights.

The Rise of Other Hochschulen.—Under similar influences and in like stages to those which prevailed in Baden and Prussia, the other German states built up their technical universities from diverse origins into the highly homogeneous type of today. Hesse laid the foundations at Darmstadt in a *realschule* in 1822 and advanced its rank successively to a higher industrial school in 1836, a polytechnic school in 1864 and a hochschule in 1877. A *gewerbe-schule* on the lines of the *Ecole d'Arts et Metiers* at Chalons was established at Dresden in 1828 and was reorganized into a polytechnic in 1851. It was given the rank of *hochschule* in 1871 and the state of Saxony installed it in a costly plant in 1875, which marked the beginning of a period of competition between the German states in the material development of these schools. At Stuttgart an industrial school was created in 1832 out of a special class for draftsmen and artisans in a *realschule*, which became a polytechnic in 1840 and a *hochschule* in 1876. A higher industrial school established at Hannover in 1831

became a polytechnic in 1847 and a *hochschule* in 1880. The state of Bavaria founded a central polytechnic school in Munich in 1823, but the school was broken up in 1827 into three, one remaining at Munich, one being placed at Nuremberg, and the third at Augsburg. The Munich school continued as a school of architecture until 1868, when it was restored to the status of a polytechnic. It was recognized as a *hochschule* a few years later, while the schools at Nuremberg and Augsburg continued as technical middle schools of the higher class. The Collegium Carolinum at Brunswick, founded by the Abbot Jerusalem in 1745 and one of the first of the German secondary schools to have a technical division, was modernized into a polytechnic in 1835 and advanced to a *hochschule* in 1877. Aachen was created as a fully developed *hochschule* in 1870, after which there was a lapse until Prussia established new technical universities at Danzig in 1904 and at Breslau in 1910 to serve its eastern regions.

Dominant Influences.—The influence of French example is apparent in the earlier years of German technical education, but a distinct national type began to emerge in the polytechnic schools under the leadership of Karlsruhe in the middle period. The rising *realschulen* pushed up the standards of entrance, while the emergence of a distinct group of technical middle schools tended to emphasize the professional aims of the polytechnics.

The pioneer work of German chemists, although largely carried out in the universities, strongly influenced the destinies of the technical schools. The laboratory which Liebig created at Giessen in 1824 became a fountain head of teaching and research. Students were attracted from all parts of the western world and Liebig's influence on his American disciple Horsford furnished much of the inspiration for the creation of the Lawrence Scientific School at Harvard. Liebig and his followers awakened Germany to the future possibilities of chemical industry, with the result that great laboratories were created in many of the university centers. The progress of the chemical industries as slow during the first half of the century and only moderate in the third quarter, but during the last quarter it became fairly irresistable. Success in appropriating chemical manufactures revealed the economic possibilities for industry in the researches of experts and Germany was quick to extend the same procedure into other realms of industrial technology. Probably the greatest contribution to industrial progress which has come out of Germany was this demonstration of the potency of *the professional organization of scientific research and of technical application*. The prompt seizure of this idea in Germany and its belated acceptance in England and France have had profound consequences in the economic and political destinies of Europe.

The influence of the *Verein Deutscher Ingenieure* must be ranked among the major forces in the upbuilding of both the technical universities and the *realschulen*. The *Verein* had its origin in a student association at the *gewerbe-akademie* of Berlin and developed into a national organization as graduates formed branches for mutual aid and education in the chief industrial centers. At the chief meeting of the *Verein* in 1864 its first director Professor Grashof, then the Rektor at Karlsruhe, made an extended report on the polytechnic schools which contained many prophetic recommendations. He advised the consolidation of the special schools of mining, building and industrial technology at Berlin into a polytechnic school, recommended that the training of foremen and technicians be handed over to a distinct group of schools and urged the polytechnic schools to take on completely the character of technical universities, training men for the highest ranks of state and industrial service and as teachers in the technical and secondary schools. He pointed out that standards are primarily determined by admission requirements rather than the length of the course and advised that the preparation for higher technical studies should be given in an *oberrealschule* or *gymnasium* rather than a trade school. He disapproved of a break in the middle of the course for a period of industrial practice and recommended a year of such

experience before admission. The Grashof report fixed the educational policy of the *Verein* for many years. Virtually all its major recommendations have since been adopted. A comparison of this report of 1864 with the address of Sir John Fowler in London in 1866 and with the Morrill Act of 1862 in the United States shows most effectively the contrast in the status and attitudes of the three nations at this middle period.

The unremitting pressure of the *Verein* was a major factor in winning full university privileges for the *hochschulen*. In equal measure it fostered the *realschulen* and contended for the equality of scientific and classical education. Its initiative was effective in 1902 in securing the removal of shop instruction from the *hochschulen* and the substitution of a year of required industrial experience. The *Verein* also took the lead in 1908 in bringing together all the major professional and industrial groups in the formation of the *Deutscher Ausschuss für Technisches Schulwesen*, or central committee on technical education. This body, widely known by the abbreviated title of *Datsch*, has rendered notable service in educational guidance, in formulating methods of training and compiling means of instruction for apprentices, advising on curricula for trade schools, in clarifying the relations of all types of technical schools in the educational system and in fostering their relations with the industries. Its annual conference on *hochschulefragen* has become the principal forum on the common problems of the technical universities. The *Verein* has sponsored many researches at the *hochschulen* through money grants and has afforded the principal channel for the disclosure of the results. Its publications on educational matters probably equal those of all the engineering societies of France, Great Britain and America combined.

The rising prestige of the *hochschulen* as a result of the support of the profession and the evidences of imperial favor won for them the backing of the new generation of industrial magnates. A brilliant example of the research institutes established by industry was set by the Kaiser Wilhelm Institute of Metallurgy at Aachen, representing a gift of $400,000 from the Krupp interests. It was largely through industrial pressure that Prussia was led to establish the two most recent hochschulen at Danzig and Breslau.

Relations with the Universities.—The rise of the *technische hochschulen* apart from the universities proper has been both praised and deplored. Viewed in historical perspective it appears as an almost inevitable result of tradition and circumstance. Had there been time for a slow assimilation of the new discipline it seems probable that technical education would have found its place in the university system, but Germany began late and the march of events was too swift for institutions bound by conservative traditions. Engineering had to fight its way up from handcraft, held in low esteem by the privileged classes. It had to win recognition as a profession against a strong spirit of guild exclusiveness nurtured in the gymnasium and university, which held a monopoly of entrance to all higher professional and state careers. Most of the universities were situated in the small provincial towns, while the polytechnics arose in the capital cities under the direct nurture of the states. To German thinking a country college is no place for an engineering school. The universities enjoyed an autonomy which made it difficult for state officials to use them for such specific ends as the training of technical functionaries and the assistance of industry. University traditions exalted "pure" or abstract learning as something far above matters of practical interest and largely disregarded the interrelations of subjects, so important in the effective training of an engineer.

The advance from the status of a *polytechnikum* to that of a *hochschule* had a symbolic significance which it is difficult for an American, accustomed to apply the term "university" indiscriminately to a Harvard, a city Y. M. C. A. and a correspondence school, to appreciate. The term *hochschule* in its modern sense is inclusive of all institutions having equal rank with the universities. It applies to institutions preparing for the recognized professions and appending to the

ministry of education rather than that of commerce. It carries with it autonomy of internal organization and the prized privileges of *lehr- und lern-freiheit*. It implies admission by the maturity certificate of the secondary schools. Far from least in importance, it fixes the status of the professors in the most preferred class of state officials.

The spirit of rivalry between the universities and *hochschulen* acted as a spur to both groups. The desire for recognition of complete equality with the universities led the polytechnics to pattern their organization after the universities as closely as the nature of their work would permit; it became a powerful unifying and standardizing influence; it led the schools to make a close alliance with the profession and the industries; and it led them to make common cause with the *realschulen*. A strong party in the technical schools stood for amalgamation with the universities; an equal group stood for complete separation, with the recognition of equal privileges. The right to award the title of engineer and the doctorate became the pivotal issue. The Swiss Polytechnic at Zurich had the former privilege long before any of the German school. When young engineers and chemists worked beside a "*herr doktor*" from a university they were often made acutely aware of an inferior status. Without the right to confer the doctorate there was little chance for the general scientific departments of the *hochschulen* to attract advanced students and to prepare men for teaching positions.

The issue between the party of amalgamation and the separatists was especially acute in the 90's, but was settled for the time by the Emperor William II in person when, at the centennial celebration at Charlottenburg in 1899, he officially bestowed the privilege of granting the degrees of *diplom-ingenieur, doktor-ingenieur* and *doktor honoris causa*. With the following words he silenced all controversy:

> "In the relations of the *technische hochschulen* to the other highest educational establishments there is no opposition of interests and no other competition than this, that each of them and every member of them for his own part should do full justice to the claims of life and science, mindful of the words of Goethe

'Neither be like to the other, but each be like to the highest. How is this to be done? Let each be complete in himself.' "

In the republican Germany of today the issue of unification has arisen anew and it is not improbable that the next decade may see the creation of one or more universities with faculties of technical science.

Changes of the Last Fifty Years.—The nature of the curricula of 1833, 1850 and 1863 has been indicated in the sections devoted to Karlsruhe and Charlottenburg. After 1870 the outreach for university privileges tended to draw the programs of the several institutions toward a common norm. The desire to facilitate the migration of students from one school to another acted in the same direction. With the advance of preparatory education in the *ober-realschule* to a level of equality with the *gymnasium* the technical schools laid aside their narrower disciplinary methods of teaching and adopted the freer methods of the universities, but subjects were taught in a less abstract manner and with far greater interconnection. Project teaching which threw the student on his own responsibility came to be especially emphasized in the technical courses of the higher years. Laboratory teaching in engineering subjects was introduced into most of the German schools at a relatively late period, although there were extensive mechanical laboratories at Munich as early as 1870. American example had a powerful influence in the development of teaching laboratories, through the report of a commission which visited leading schools in the United States after the Congress of Engineering in connection with the Columbian Exposition of 1893. Previous to this time most of the schools had only private research laboratories which had been installed on the initiative of individual professors. Charlottenburg alone spent $900,000 in installing teaching laboratories between 1893 and 1897. Internal instruction in shop practice had been given in many of the *hochschulen* before 1900 in order to compensate in some measure for the lack of industrial experience by the students. Reference has already been made to the initiative of the *Verein Deutscher Ingenieure* in securing

the abandonment of shop teaching. It is worthy of note that a number of German professors of engineering who inspected American schools in 1893 expressed strong disapproval of much of the shop instruction they had seen. Before 1900 many of the curricula had been three years in length, but at that time practically all were placed on the uniform basis of four years.

The technical universities have offered an increasingly wide range of instruction in recent years outside of strictly scientific and technical fields. There has been no attempt to encroach on the functions of the universities, but rather to broaden the training for technical professions on the humanistic side, especially in the realm of political and social studies. As one eminent *rektor* put the case:

"Technical education designed exclusively to meet the demands of a special occupation would isolate the technicist from the civic life by which he is surrounded and would alienate him from the ideal interests of society."

There is now a growing tendency to introduce the teaching of industrial organization and management, including the new division of psychotechnics.

The expansion of research activities has been especially marked since the right to confer the doctorate was granted in 1900. The German technical university of the present is far more than a teaching institution—it is the major creative agency of the nation for the advancement of all technical sciences and arts. The high importance of this role in the national life is well epitomized by the motto of one of Germany's great technical societies, "*Die Technik ist Deutschlands wirtschaftliches Schicksal*"—technical science is Germany's economic destiny.

D. Switzerland

The Swiss constitution of 1849, which was designed to strengthen the Confederation after a severe economic crisis, gave it the right to establish a Federal Polytechnic School and a university. Hitherto all public responsibility for education had been vested in the several cantons. Thriving technical schools of a practical character had been built up under cantonal auspices. A special school for industry, public works, building and the arts was founded privately in 1853 by five professors in Lausanne on a plan resembling the *Ecole Centrale* of Paris. About twenty years later it was taken over by the Canton of Vaud and became the present *Ecole d'Ingénieurs* of the University of Lausanne, serving principally the French speaking area.

The founding of the Federal Polytechnic School may be ascribed to the feeling that only the highest grade of scientific direction would enable Switzerland, a country of crowded population but largely devoid of raw materials, to maintain its industrial position in the presence of its larger and more generously endowed neighbors. The School was established at Zurich in 1854. The city supplied it with an admirable building and with much of its original equipment, while the Confederation made an annual subvention of 250,000 francs toward its operating expenses. This was a large sum for the times. The Polytechnic had no hampering traditions and was free to profit by the experience of the earlier schools of France and Germany. By leaving all preparatory and vocational education to the cantonal schools, it was able to place its whole program on a professional plane equal to any university. Furthermore it had the right, not then possessed by any German institution, to confer the professional diploma of engineer. The Polytechnic brought together a staff of notable qualifications and soon attracted students from all parts of the world. Without doubt it exercised a strong influence on the early development of engineering education in Italy and on the later evolution of the *hochschulen* of Germany and Austria.

E. The United States

Origins and Characteristics.—Engineering education in the United States is the outgrowth of a popular movement early in the last century to promote "the application of science to the common purposes of life." There was no thought in the

beginning of creating any formal discipline for the profession of engineering, the aim was rather "to give farmers and mechanics such a scientific education as would enable them to become skillful in their professions." Rensselaer had scarcely begun its pioneer work as a school of practical science when the advent of the railroad opened a new chapter in the history of American engineering. The engineers of the earlier decades, a scattered group of land surveyors, builders of roads, canals and bridges, and practical constructors of machinery, had been largely self-taught. With the railroad came a demand for engineers with a greater mastery of the scientific resources of the art. There was no foundation for a scheme of training by pupilage, as in England, and the engineering school arose by simple necessity. Models were borrowed from France, where higher technical education was highly developed, and the effort to apply science to the common purposes of life passed rapidly into the special form of a professional discipline for engineers. This in turn was quickly assimilated into the newly developing university system.

The leaders of the early years were not statesmen nor active practitioners, but scientists and educators. In their hands engineering education acquired its traditional freedom from outside regulation. The consequences of the early fixation of technical education as a professional discipline on the university level have not been wholly good. Engineering colleges have been multiplied in America as in no other land, but other types of technical schools have been largely eclipsed. The training of artisans, foremen and technicians, and possibly of the higher officers of industrial production as well, has been neglected in favor of the training of professional engineers. A democratic desire to give "all of the boys a chance to get to the top" has resulted in indefiniteness of aim and failure to make a rational division of the functions of technical education among different types of schools. Measured by an international scale the chief virtue of American engineering education is probably its accessibility, its chief defect vague objectives and uncertain standards.

The Period of Germination.—The War of Independence threw the new-born American states back on their own economic and intellectual resources. It was a pioneer age, when men prized versatility above specialized training and practical resourcefulness above the refinements of science. Inventions multiplied and industries developed in the hands of ingenious mechanics. A handful of engineers trained abroad and a few self-taught Americans executed the simple public works. A little coterie of intellectuals who had come under French influence, Franklin and Jefferson among them, visioned the possibilities of science and labored for its advancement, but the established colleges of the day held fast to the exclusive classical traditions brought over in the early colonial period from Cambridge and Oxford. Efforts for the practical use and advancement of science came largely from popular sources, from groups of merchants and mechanics who formed institutes, founded libraries and offered premiums for inventions and for improvements of process or design.

A glance at the educational conditions of 1800 will show how impossible it was for applied science to become rooted in the existing educational system. A bare half dozen of the twenty-one colleges had made any provision whatever for the teaching of the physical sciences and that against the open hostility of the ruling academic party. There was no extended system of secondary education and the scattered Latin and grammar schools were entirely dominated by the classicists. Professional schools of law, medicine and divinity were just beginning to displace the more casual training by pupilage. A system of university education, in its modern comprehensive sense, did not exist. Tradition left virtually the entire field of education to private, sectarian or local initiative. To make science an effective aid to production a new type of school and a new type of teacher were needed. While colleges and public authorities remained deaf to the rising chorus of demand for practical scientific information, it remained for men of affairs to take an effective initiative.

Pioneer Efforts.—The earliest American effort to create a school of practical science was made in 1821 by R. H. Gardiner and a group of fellow townsmen of Gardiner, Maine. Aid was obtained from the state legislature in establishing the Gardiner Lyceum

> "to give farmers and mechanics such a scientific education as would enable them to become skillful in their professions."

Gardiner enlisted the aid of a young Bowdoin tutor, Benjamin Hale, who had turned from theology to science and who threw himself into the work of organizing the school with missionary zeal. The school was opened in 1822 with a two year course of instruction. In 1824 Hale reported to the backers:

> "The winter classes are already established in surveying, in navigation, in carpentry and civil architecture, and in chemistry."

Hale's addresses in quest of financial support show plainly that he foreshadowed the modern schools of technology. Unfortunately the times were not ripe. Legislative aid was withdrawn and the school faded out. Hale went to Dartmouth and was largely influential in laying foundations for its later work in the Chandler Scientific School.

This effort at Gardiner was not an isolated event. Stephen Van Rensselaer of Albany, land owner, capitalist and leader in public affairs, took steps in 1823 to establish a school at Troy

> "for the purpose of instructing persons who may choose to apply themselves in the application of science to the common purposes of life. My principal object is to qualify teachers for instructing the sons and daughters of farmers and mechanics, by lectures or otherwise, in the application of experimental chemistry, philosophy and natural history to agriculture, domestic economy, the arts and manufactures."

The genius behind this proposal was Amos Eaton whom Rensselaer had employed to make certain surveys and by whose scientific capacity and practical sagacity he was deeply impressed. As a lawyer, civil engineer, geologist, botanist, chemist and educational pioneer, Eaton combined a Baconian versatility in science with a Yankee's capacity for practical affairs. Under the direction of Eaton the Rensselaer School, as it was first known, developed in the course of twelve years into a professional school of civil engineering, the first in the English-speaking world.

An organization of citizens of Philadelphia brought forward in 1826 a plan for a polytechnic and scientific college, which should not require Latin and Greek for entrance and should give instruction

> "in every branch of knowledge requisite for the agriculturist, the mechanic or manufacturer, the architect, the civil engineer, the merchant and other man of business"

but the project led to no tangible result.

The First Engineering Schools.—The Military Academy at West Point rightly claims the place of seniority among the American schools of applied science. Its beginnings are uncertain. Originally a corps of engineer cadets and scarcely more than a name before 1812, it began to emerge as a school of advanced character when Col. Sylvanus Thayer became Superintendent in 1817. Thayer had made a study of the military schools of Europe and the program and regime which he introduced plainly show the influence of the *Ecole Polytechnique* of Paris. Chemistry, physics, higher mathematics and descriptive geometry were taught and engineering applications were considerably developed.

While the Rensselaer School continued for many years to fulfill the purposes of its founder by training teachers of natural science and left a great impress in that field, its chief work passed rapidly into the realm where it won its great renown, that of civil engineering. Instruction in engineering made its way into the curriculum at Rensselaer by gradual stages. The courses of 1825 included "land surveying, mensuration, measurements of the flow of water in rivers and aqueducts." The following year there appeared "hydrostatics and hydrodynamics" and "calculations upon the application of water power and steam." In 1827 reference was made to "land surveying and general engineering." The term "civil engineering" appeared first in the catalog of 1828. In 1835 there was a distinct program of instruction

in "engineering and technology" and the degree of Civil Engineer was bestowed for the first time on a class of four. The course of study in this early period occupied a single year. There are indications that Eaton visualized a graduate school for men who had previously completed a liberal education. While this ideal was never fully realized, the students were mature and there was a goodly proportion of college graduates among them.

The Rensselaer Polytechnic Institute.—Amos Eaton left his impress on engineering education principally through his disciple and successor, B. Franklin Greene. Upon succeeding Eaton as Director in 1846, Greene undertook a complete reorganization of the school. He visited leading institutions of Europe and analyzed their curricula in the search of models. On his return he proposed a plan for a comprehensive polytechnic institute which would deal "with all matters cognate to architecture and engineering" and at the same time continue the original work of the Rensselaer School in training teachers of natural science. Without doubt Greene was the first man in America to submit the problems of education for the technical professions to thorough investigation and analysis. In essential matters his conclusions remain sound today. What he visualized was an educational discipline complete in itself, not narrowly utilitarian but "adapted to the complete realization of true educational culture."

Greene, more than any other man, gave to engineering education in America its distinctive form and character. The plan for a group of "schools" to prepare for all the technical professions which Greene had projected was beyond the means then available. In consequence only the branches of civil and topographical engineering were at first developed. The name Polytechnic Institute which was adopted in the reorganization of 1849 signalized the ascendancy of professional training for engineering over the original aims of the school. Greene found his models in the highly developed technical schools of Paris. The new curriculum followed the general plan of that of the *Ecole Centrale des Arts et Manufactures.*

A comparison of the Rensselaer curriculum of 1850, as shown below with that of *Ecole Centrale* of the same period, as shown on page 16, indicates that Greene borrowed more from the form than the content. The distinguishing feature was the parallel sequences of humanistic studies, mathematics, physical sciences and technical subjects which have marked American engineering curricula to this day. Experience soon showed that the new curriculum of three years was in advance of the prevailing preparatory education. To close this gap a "preparatory division" of one year was then provided, but the distinction of name gradually disappeared, leaving the integrated four-year program which has since become the widely accepted norm.

RENSSELAER CURRICULUM IN CIVIL ENGINEERING, 1849–1850

Year I	Year II	Year III
English	English	English
Foreign language	Foreign language	Philosophy of mind
Algebra, geometry, trigonometry	Analytics, calculus	Mechanics
Geometrical drawing	Descriptive geometry, machine drawing	Descriptive geometry, perspective, topographical drawing, stereotomy
General physics	General physics	Industrial physics
Botany	Chemistry	Metallurgy
Surveying	Zoology	Practical geology
	Mineralogy	Mining
	Geology	Geodosy—trigonometrical, railroad and mine surveying
	Topographical and hydrographical surveying	Machines
		Constructions — theory of structures, bridges, hydraulic works, railways

Assimilation by the Universities.—The example set by Rensselaer was soon followed by other institutions. Union College introduced the teaching of civil engineering in its scientific department in 1845. Dartmouth established the Chandler Scientific School in 1851, intended by its benefactor "to be a school of the industrial vocations." The University of Michigan, the pioneer among the state universities of the nearer and farther West, began instruction in engineering in 1852. Michigan owes much to the foundations laid by DeVolson Wood, a former country school master who had worked his way through Rensselaer by teaching in the preparatory division. On receiving his degree of Civil Engineer in 1855, Wood decided to locate in Chicago. He stopped off quite casually on his way west to have a look at the University of Michigan. A newly appointed professor of civil engineering had failed to appear and the authorities were in a quandary. Wood was asked to stand by for a few days as a stop-gap and he remained seventeen years. Brown was also early in the field. One of its first engineering graduates, R. H. Thurston, C.E., 1859, later became a dominant figure in mechanical engineering through his teaching at Stevens and Cornell and his many researches and publications.

Harvard and Yale both took steps to create schools of applied science in 1847. Through the influence of Prof. Eben N. Horsford, a Rensselaer graduate, who had worked with Liebig at Giessen, Abbott Lawrence was led to establish the Lawrence Scientific School at Harvard. His gift of $50,000 for this purpose is said to have been the largest yet made to an American college by a living donor. It seems that Lawrence had clearly in view the establishment of an engineering school. His letter of instruction enjoined that

> "The three great practical branches to which a scientific education is to be applied are: 1st, engineering; 2d, mining in its extended sense, including metallurgy; 3d, the invention and manufacturing of machinery."

It was a long period before Lawrence's purposes were adequately realized at Harvard. Aggasiz the naturalist and Horsford the chemist became the first professors of the new school. Their interests lay in other directions and the college as a whole was openly hostile to technical studies. The first engineer was graduated in 1854 and there were few others before 1860. In the first forty-five years of its history the Lawrence' Scientific School graduated but 155 engineers in all. It was not until 1892 that the teaching of engineering was developed with vigor at Harvard. Harvard's tardiness in realizing Lawrence's intentions appears to have been a major factor contributing to the establishment of the Massachusetts Institute of Technology on an independent foundation in 1860.

Applied science at Yale owes much to the early inspiration of Prof. Benjamin Silliman, who began his long and fruitful career in 1801. Two chairs of applied chemistry were established in 1847 as the nucleus of a department of "Philosophy and Arts" directed by Prof. John P. Norton. The chair of mathematics and civil engineering was created in 1852 and the chair of metallurgy shortly after. In 1856 a three-year course in civil engineering was in operation and a course in mechanical engineering—the first in America—existed on paper. The scientific school was severely handicapped by lack of funds and by the avowed hostility of "the college proper." Its prosperity increased rapidly after 1860, when Joseph E. Sheffield came forward to give it a home, an endowment of $100,000 and the name Sheffield Scientific School.

The Turning Point.—The period leading up to 1860 had been one of difficult pioneering. Practical men—Franklin, Jefferson, Gardiner, van Rensselaer, Lawrence, Chandler, Sheffield—grasped the economic possibilities of science and technics while the great body of educators remained hostile or aloof. How often "the children of this world are wiser in their generation than the children of light"! There could be no large development until the monopoly of classical learning was broken, nor could this come until the early conception of the nature and objects of education and of its relations to the state had been profoundly altered. By 1860, thanks to the work of Horace Mann and other pioneers, foundations had been laid for a comprehensive system of public education on advanced lines. The Morrill Land Grant Act of 1862 was symbolic of this deep change of public attitude. Morrill's first bill had been vetoed in 1857 through the opposition of the states' rights party, but the Congress of 1862 was a northern body, pledged to the cause of farmers and mechanics, and ready to put the resources of the Federal government behind the popular movement "for the application of science to the common purposes of life" which had been gathering momemtum from the days of Gardiner and van Rensselaer. The impetus of the Morril Act was felt by private as well as public institutions. In the space of a single decade, from 1862 to 1872, the number of engineering schools increased from six to seventy, a rate of expansion without parallel.

Leaders in the Period of Expansion.—It was a fortunate circumstance that this period was ushered in by the establishment of three notable institutions which helped to supply men and models for the many others soon to follow. The Massachusetts Institute of Technology was largely the creation of William Barton Rogers, an educator and geologist of note, who secured the backing of a group of influential citizens of Boston and the financial aid of the State in a broadly conceived plan

> "for the purpose of instituting and maintaining a society of arts, a museum of arts and a school of industrial science, and aiding generally by suitable means the advancement, development and practical application of science in connection with arts, agriculture, manufacture and commerce."

The Society of Arts, intended for the popular diffusion of scientific knowledge, began its work in 1862. The opening of the school of industrial science was delayed by the war until 1865. The museum yet remains to be established. The name "Technology" was proposed by one of the original backers, Dr. Jacob Bigelow, to mark the distinction of purpose from the pursuit of science as a form of "polite learning." The Institute has been the broadest in its scope of any of the American schools of applied science, embracing architecture, biology, chemistry, physics, geology and naval construction in addition to the several branches of engineering. In its size and scope it has resembled the great technical universities of Germany more closely than any other American institution. One of its notable contributions to the early history of engineering education was the introduction of individual laboratory instruction in the physical sciences.

The iron and coal industries of the middle states and metal mining in the West began to develop rapidly about 1850. The mineral industries were mainly dependent on Europe for men of scientific training and the *Bergakademie* at Freiberg counted many Americans among its students for several decades. Professors Chandler and Joy, chemists, and Eggleston, metallurgist, took the principal initiative in creating the first American school of mines at Columbia in 1864. Chandler is said to have adapted the original plan of studies from the *Ecole des Mines* of Paris; the curricula of both schools covered a period of three years and consisted wholly of scientific and technical studies. At a later period the School of Mines lengthened its program to four years and broadened it on the humanistic side. Columbia supplied the prototype for most of the schools of mines and metallurgy which sprang up in the period between 1865 and 1880.

The Morrill Act opened the way for the rapid expansion of engineering education throughout the North and the West. Within a period of twenty years the federal government made grants from the public domain which considerably exceeded the area of Great Britain to aid the states in establishing colleges of agriculture and the mechanic arts. One of the most influential of the early land grant institutions was Cornell University, intended by its founder and chief benefactor to be "an institution where any person can find instruction in any subject." Cornell, though essentially an independent institution, received the land grants of the State of New York under a liberal policy which encouraged the older and the new educational disciplines to develop on even terms.

There seems to have been a good deal of confusion in the early land grant colleges as to the character and purposes of the schools of "mechanic arts." Andrew D. White, Cornell's first president, probably did more than any other one person to establish the interpretation which has since widely prevailed. When Cornell opened its doors in 1868 some of the trustees advised making the school of mechanic arts a manual labor college of inferior rank. There was a small waterpower on the campus which they proposed to use in operating a manufacturing plant employing student labor. President White thought otherwise. What he visualized by education in the mechanic arts was a training "in every way equal to the learned professions." He visited Europe and made a

close study of technical education. On his return he sought out men of distinction like Morris and Sweet for the professorships, personally raised funds and purchased the first equipment for the engineering shops, and later brought Thurston from Stevens to carry on a great constructive work in mechanical engineering. The influence of Cornell in the period of the great growth of the engineering colleges in enrollments and resources, extending from 1870 down to 1900, both by direct example and through her many graduates who went out as organizers and teachers, is one of the most notable of the recent chapters in the history of American higher education.

1870 as a Transition Point.—The year 1870 marks the boundary between two quite distinct periods of development. The earlier or formative stage had been marked by the creation of new and distinctive schools and programs; its dominating personalities were more often scientists and publicists than engineers; and its chief aim had been the training of civil engineers to meet the problems of an era of rapid geographical expansion and of growth in urban population. After 1870 came a period of expansion and ramification, based on the models already created; engineers of distinction took an increasing leadership in education; an American literature of engineering began to develop through the authorship of leading professors; the engineering profession took on solidarity and began to influence the scheme of education; and an extraordinary expansion of industry created a wide field for mining, metallurgical and mechanical engineers.

There was also a marked change of educational method in this transition period. In the earlier years there had been little laboratory teaching; practical exercises in the drafting room and the field, together with occasional demonstrations by teachers of the sciences, sufficed to round out the didactic teaching of the class-room. The most noteworthy feature after 1870 was the great development in laboratory methods of teaching, a field where American leadership has been especially marked. Rogers had projected laboratories for physics, manipulative and analytical chemistry, metallurgy and mining, and industrial chemistry in his plan for the Massachusetts Institute of Technology. With the aid of his associates Pickering and Eliot the laboratory teaching of the physical sciences was placed on a sound basis in 1869. The first engineering laboratory in America was doubtless that established by Thurston at Stevens Institute in 1871. Thurston went to Cornell in 1885 and was largely instrumental in building up the engineering laboratories there. His influence on the development of curricula and methods of teaching in mechanical engineering probably exceeded that of any other American educator.

The early American mining schools were established in eastern centers and suffered from the handicap of being remote from the chief seats of the industry. The German mining academies at Freiberg and Clausthal were located in important and varied mining areas and had worked out an intimate combination of teaching and actual contact with mining operations. Paris had achieved an approximate equivalent through the required *stages* to which its students were assigned in the vacation periods. The London school did its work under government regulations which required the students to spend a certain period as active miners before they could receive their diplomas. The American schools sought to meet this handicap by installing mining laboratories in which the actual operations of the industry were simulated as closely as possible. Professor Runkle is said to have conceived the plan of such a laboratory for the Massachusetts Institute of Technology when conducting a scientific expedition to the Rocky Mountains in 1872.

The Development of Shop Instruction.—The early courses in mechanical engineering were concerned chiefly with the design of machinery and with the technology of the workshop. The problems of power production and application on a large scale did not begin to assume a major importance until the 80's. The shops rather than the laboratory were the seat of the early efforts at practical instruction. Worcester Polytechnic Institute began its work in 1868 with a small manufacturing plant on the premises, in which the students worked with practical journeymen in commercial production. The original purpose of the school, that of training mechanical superintendents, was preserved for twenty years, after which the school became a general college of engineering. During that period more than a quarter of the required work was devoted to shop practice. The Cornell shops, which had a wide influence in fixing the general norm among the land grant colleges, were installed in the early 70's solely with a view to instruction. The influence of President White and of Professors Morris and Sweet has already been referred to on page 69. Shop practice was first mentioned specifically in the Cornell catalog of 1874–75 and was then included in each of the twelve terms of the course. Shop work was still required through the entire course in 1898, but by 1915 the requirement had been reduced to five semesters. Thurston was evidently greatly impressed with the system of shop training he found in operation when he came to Cornell in 1885, for he wrote:

> "The progress which can be made by the skillful application of the system of graded exercises is simply astonishing to one who has not seen it in operation; and it is probably well within bounds to assert that, by means of this method, the young aspirant can be carried further along in his trade in a year, than by the old methods and lack of system in apprenticeship he could go in the whole period of the seven years for which it was once customary to write the indenture."

It is interesting to note that Frederick W. Taylor of scientific management fame severely criticized that statement and thought it would be more appropriate to reverse the ratio. The methods of shop instruction introduced at the Massachusetts Institute of Technology owed much to the exhibit of the Russian school shops at the Centennial Exposition of 1876.

The Trend toward Scientific Training.—The early emphasis on shop-work was symptomatic of the urge which the schools felt to make their training as practical as possible. The acceptance of formal education by the profession and the industries was not won without a long struggle. Traditions carried over from pioneer days and reinforced by British example and influence kept alive the distrust of theory and emphasized its detachment from practice. The early discussions of engineering education in the technical press and by the engineering societies abounded in criticism of this nature. Engineering teachers felt the call to demonstrate their competency by undertaking collateral practice. A strong scientific spirit and zeal for research were slow to develop in many of the colleges. With the opening up of the field of electrical engineering in the 80's followed by that of chemical engineering in the 90's, there was a distinct swing away from the effort to make engineering education as practical as possible in the direction of making it more scientific. Most of the earlier teachers of electrical and chemical engineering had not been trained as engineers but as physicists and chemists. Through this process of assimilation engineering was enriched and fertilized with a scientific spirit. Toward the end of the century there was a perceptible gain in the volume and quality of research activity. In the same period the educational process began to lose some of its earlier character of a fairly self-contained professional discipline and to take on that of an introductory stage of scientific formation. This movement was greatly advanced by the close bond between the schools and the newer industries which had developed directly out of scientific research and technique and notably the electrical industry. An understanding arose, almost from the beginnings of the industry, under which the employer assumed practically the entire responsibility for the practical training of the student and the college was left free to devote itself to the scientific foundations.

Contemporary Movements.—Since the turn of the century three movements have stood out with special prominence. The first is the upbuilding of the cooperative system, instituted by Dean Herman Schneider at the University of Cincinnati in 1906, which has been discussed at length in Bulletin No. 12 of this series. The division of the student's time between instruction and practice in practically equal periods is not new, as the sandwich system has been in use in Scotland for more than fifty years, but the provision of regularly scheduled intervals of periods of instruction in college and of supervised and correlated experience in industry was an essentially original feature. The second movement has been the greatly increased emphasis on the economic and management phases of engineering under the inspiration of the pioneer work of Frederick W. Taylor and his followers. This movement has reached such proportions that the question has been raised whether the major function of some, if not all, of the engineering colleges should be to train men for industrial management rather than the technical work of engineering. The third outstanding movement has been a great increase of engineering research and post-graduate study. Prior to 1900 there were almost no graduate students of engineering; the doctor's degree in engineering was seldom earned; engineering teachers devoted such free time as they could command to collateral practice; authorship was largely a process of compilation and editing; and the engineering schools had little direct share in the advancement of the art. The movement toward creative activity in engineering schools still lags far behind its chief examples and sources of inspiration, the industrial research laboratories of America and the technical universities of Germany, but its progress has been noteworthy.

Guiding Influences.—The American system of engineering education is a complex of borrowed and indigenous elements: the collegiate plan of organization and most of the traditions of the professoriate can be traced back to the earlier arts colleges and the older universities of England; the emphasis on interrogatory rather than expository forms of teaching goes back to the old English grammer schools; early engineering curricula were derived from French models; from France also came the professional school of engineering rather than the British scheme of pupilage; Russia supplied early models for the teaching of manual arts; and German research ideals and methods have made a profound impress in recent years.

The genius of the American schools has been more adaptive than creative, but in two respects at least they have exercised a conspicuous leadership—the introduction of individual methods of laboratory instruction and the provision of distinctive training in the economic and management phases of engineering.

In no other country have the engineering schools been so free from outside domination. They owe little to statecraft other than the provision of means for their extension and support. They owe little to the organized engineering profession except the benefits of occasional criticism of their aims and methods. They owe little to the industries except an ever-widening field of employment for their graduates. To a striking degree, these schools have been left to work out their own destiny and to fend for themselves. This has been the source of both strength and weakness. There has been complete freedom for educational experimentation and innovation which, when exercised, has justified itself abundantly through a number of major advances. On the other hand the leaving of all initiative to individual institutions, with no coordination of policy, has resulted in failure to work out a well-rounded national system of technical education in its several natural divisions.

The engineering school has remained largely a thing apart, a seat of individual effort and of individual discipline, and has not achieved in America as in Germany a large place in the strategy of social progress. Is this its destiny? No doubt the engineering school will long remain primarily a teaching institution and a place of research for inquiring minds; enlightened and inspired individuals will be its most precious gift to society; but it is scarcely conceivable in an essentially technological civilization that the school of technical science should be content to remain almost wholly a transmitting medium, with only a minor share in the creation of knowledge and with little or no share in the shaping of social institutions.

PART V. THE AMERICAN SCENE

This final section is an attempt to view, and in some measure appraise, the higher technical education of the United States in a spirit of detachment, by comparison and contrast with the European systems which have been briefly described.

A National System Without Plan.—The higher forms of technical education have developed sporadically in the United States and without an underlying plan. In the absence of any federal authority or any central control of technical education by the states, each institution has developed with complete freedom. It is surprising, therefore, to find so little variety of types of instruction and of levels of entrance and completion among the one hundred fifty colleges of engineering, and so few substantial technical schools of any other type. Tradition, the influence of early models and imitative growth evidently may impose even greater uniformity than bureaucratic authority. The aim of the original technical schools "to promote the application of science to the common purposes of life" was comprehensive but vague, and was quickly transformed into more precise but limited terms when the advent of the railroad created a specific need for engineers with a scientific training. The new discipline, formed on French models, was quickly assimilated by the collegiate system as an alternative to the older discipline in liberal arts. This transpired in a formative era of our national educational system when a simple but artificial order was being standardized—the elementary school, the secondary school, and the college. Technical education fitted into only one of these compartments, the college. There it grew vigorously, but the total result has been most one-sided.

Moreover, one dominant type tended to overpower all others. Repeated attempts to create and maintain other forms of technical schools, with briefer, more practical and more flexible programs, have ended in most cases in final absorption into the college group. Being neither primary schools, secondary schools nor colleges, these less conventional technical schools seemed to have no place in the national system. Their graduates had no credentials of wide acceptance, and no professional or educational bodies of wide influence extended recognition or encouragement. Immigration supplied a steady stream of skilled labor and of trained technicians. As long as America provided means whereby her native youth might be trained for the recognized engineering professions she was content.

The Directive Forces.—The guiding forces have come almost wholly from within the system itself. The early pioneers were educators and scientists who visioned the potentialities of applied science, rather than statesmen bent on economic reform or practitioners seeking to train subordinates. They did American education an inestimable service by breaking the monopoly of classical learning, introducing more concrete forms of instruction and directing it to economic ends. The State has had little formative influence; the Morrill Act provided means for a vast extension of technical education, but did little in itself to create a type. The technical professions and industries have been consumers and critics rather than responsible guides. The traditions of the engineering profession have been individualistic, its definitions loose and its code of qualifications based solely on ability to perform. These conditions have reacted strongly on technical education, but in a negative manner. It has been left to grope its way and fend for itself, in marked contrast to the technical education of France, Great Britain, and Central Europe.

The Central Aims.—Technical education abroad is essentially national in plan and in outlook; it is definitely tied in with the economic system; and is controlled by public authorities and the organized professions. American technical education is individualistic in its aims and ideals; its primary concern is with the welfare of the student, its secondary aim to recruit a group of professional callings; in consequence it is at best only semi-selective and semi-professional. American engineering colleges have less precise aims and functions than similar institutions abroad. They can not fit men into pre-determined molds nor form them to conventional professional patterns; the ideal must be one of personal adaptability —in some measure the ability to go anywhere and do anything, not always with ultra-expertness, but sufficiently well for practical purposes. They can not, if they would, put aside their task of personal guidance and social adjustment, their concern with the entire life plan of the student as an individual, for which little need exists in the highly stabilized societies abroad. The chief danger, however, seems to lie in the opposite direction, that a benevolent paternalism may be overdone and the compromise between the ideals of social adjustment and those of a selective professional discipline may result in the technical professions being outranked intellectually both at home and abroad.

Quantity Production and Intellectual Standards.—The burden of quantity production for the ordinary technical, supervisory and commercial needs of industry weighs heavily on the American engineering colleges. Efforts to create highly selective schools of distinctly superior scientific standards have fared badly as a rule. No institution is so outstanding that the success of such an effort could be taken for granted, as long as the public mind differentiates the engineering schools chiefly by the excellence of their plants and the size of their enrollments, rather than the eminence of their teachers, the scientific quality of their instruction or the merits of their research. The distinction which is universally made abroad between preparation for the practical direction of industry and for its intellectual leadership, has not been recognized—America has neither *Arts et Metiérs* nor *Ecole Polytechnique*. One result has been that the production side of industry has been seriously underrecruited; another that in the constructive industries America has been dependent for the highest forms of analytical and design ability on men trained abroad. Technical research has depended in large measure on men of European training or upon men trained in pure science. These conditions are gradually being corrected, but American engineering is still far from being self-sufficient on its higher intellectual levels.

It may be remarked that American technical superiority in the realm of mass production and automatic processes has been achieved almost wholly within industry itself and owes little directly, or perhaps even indirectly, to the schools of engineering.

Preparatory Education.—The demand for educational privilege and the problem of assimilating a population of heterogeneous origins have been so insistent that the entire educational system has been expanded with little regard to the availability of a qualified teaching force. The pressure has been acute in secondary education and its effects have been severely felt in the colleges. It is a safe generalization that the standard of intellectual and cultural qualifications among secondary teachers abroad is quite equal to the average found in our higher institutions. Considering that secondary education abroad is a selective process, definitely pointing to intellectual pursuits, covers a period of six to nine years, is organized on a much more intimate scale, and involves much greater continuity of subject matter, it is not surprising that the levels of intellectual achievement are decidedly superior to our own. Our public secondary schools disclaim a predominantly intellectual purpose, and are preoccupied with exploratory processes and social guidance activities, intended to fit young people into spheres of life quite unlike those in which they were born and reared.

It is probably too much to ask that our preparatory education shall reach the levels of intellectual efficiency of the highly selective systems of Europe, but it seems clear that the present levels of achievement at the age of twenty or twenty-one could be reached at eighteen or nineteen by young persons of superior endowments without sacrifice of youthful vitality or zest. A study of European experience lends strong support to the conclusion that the most effective means to a broader scientific and humanistic education for engineers, which every one agrees is needed, is through more effective secondary education and more selective admission, rather than delayed entrance into technical studies and pursuits. World wide experience and the clearly expressed judgment of the engineering profession indicate that the age level between sixteen and nineteen is a normal period for beginning technical education, and

that from twenty-one to twenty-three for entrance into practical pursuits. The present quality of our mathematical and scientific preparation is so low that it constitutes the greatest handicap of our engineering colleges in comparison with similar institutions abroad.

Curriculum.—Conservatives who hold to an orderly discipline in technical education may find assurance in the fact that Europe has discovered no effective substitute, even where the greatest autonomy prevails in purely academic studies. Radical departures from the organic unity of a curriculum which begins with the mathematical, physical and natural sciences and proceeds from the basic technical sciences to their engineering applications, such as a completely inductive case system, a sequence of job assignments or a complete submerging of the general sciences into the technical branches, are still to be regarded as experiments, postulated on educational theory rather than experience. Europe has not yet developed a phobia for preparatory studies on the theory that all education must grow out of immediate life experience. Considered purely as a formal educational structure the American curriculum will stand comparison with any abroad. It is distinctly broader than the English or Scottish examples, but the merit is more apparent than real when the limitations of our secondary education are considered and allowance is made for thoroughness of mastery and coordination of the basic sciences. It is far more elastic than the French scheme of courses with specialized objectives, as it should be considering the later career choices of American youth. It is more closely knit together than the German programs with their vast proliferation of specialized applications.

There can be little criticism of the sequence of studies, except that mechanics is introduced so late in many cases as seriously to hamper and restrict the development of the engineering subjects. So certainly is the place of mechanics the key to time economy, that it would seem worth while to restudy completely the sequence of topics in mathematics and the relation of mechanics to general physics with a view to its earlier introduction. Time allotments to mathematics, physics and chemistry are probably as large and the present treatment as encyclopaedic as can be justified for the average student, but higher standards of mastery of the comparatively few key principles are imperative all along the line, and provision should be made for more extended study of the general sciences by selected superior students. The latter end might appropriately be secured through advanced elective courses, adapted in content and pace to superior students, which may be elected as substitutes for courses in technical applications.

The limited study of engineering on its constructive side—in which we lag far behind the continental schools—is probably regrettable but inevitable. We can not afford the time, too few of our students are preparing with certainty for design work, our processes of fabrication are unsuited to "custom built" structures, and very few of our colleges have, or perhaps can have, fully qualified teachers. No solution of this problem is in sight but to make this phase of an engineer's education part of the professional novitiate, either by some cooperative plan between employers and selected graduate schools or by systematic training within industry. Here the electrical industries have pointed the way for the benefit of all.

Specialization.—The author is no advocate of a common curriculum for all engineers, but believes that differentiation on broad lines which parallel the major divisions of the technical professions is both expedient and sound. All European experience supports this view. The multiplicity of curricula and degrees reported by the U. S. Bureau of Education is less alarming when one recognizes that seventy per cent of all engineering students are in three major curricula and 83.5 per cent definitely within the areas of the five principal professional branches. The German plan of holding to a few major "faculties" and providing group options in the final years, some specialized and others broadly theoretical, seems wise and sound. The French plan of specialization by schools seems to imply a purely teaching aim. Certainly it has not engendered research through what has been called "the mutual fecundation of the sciences."

Teaching Processes.—In nothing does the essential juvenility of our higher education reveal itself so fully as in the text-book, daily assignment, recitation, written quiz, piecemeal grading system of instruction, and in our eager effort to compensate for the student's defective mastery of the processes of learning by one and another pedagogic device. In the effort to make up for deficiencies of preparation, the indefinite aims of students, the lack of social and economic urges to educational achievement, as well as the absence of intellectual traditions in society and of standards of scientific competency in the technical professions, the engineering colleges of America have felt compelled to resort to a driving process. The student has less freedom and more routine than his European confrere. He probably does not work any harder, but he works under a different regime and under different urges. He is not an independent spirit striving for a large but distant goal and imposing on himself the discipline needed to attain it, he is too often a harried quantity producer trying to keep abreast of his quota of daily and weekly tasks.

The author is convinced that education based on systematic execution of concrete tasks, interspersed with direct expository teaching, discussion and reflection, has merit—one has only to spend a day at a French *Ecole d'Arts et Metiérs* or a German *baugewerkschule*—but it belongs in a school definitely organized to that end, working on an all-day program. The actual methods of our engineering colleges, while less efficiently organized because not so clearly visualized, do not work badly with industrious students of rather mediocre ability. There is plenty of European testimony to the effect that we accomplish more with our average students than any other system. The superior student, whose originality and imagination are too often sacrificed to mere industriousness, is not so well served. Sweeping statements are always partially untrue, and exceptions to these observations are numerous, but the author is convinced that they are broadly true. The root of the problem is in the teacher, too often overloaded and only half prepared for much that he is expected to teach, who perpetuates the system of which he is the product and too often knows or imagines no other. We are not, as a rule, effective lecturers and have made little study of the art of giving instruction to large groups. Our students expect to be taught, rather than to learn independently with the guidance and coordination that an able lecturer can supply.

Our experimental and practical teaching is today probably as effective as any in the world. This statement may be qualified, however, by the comment that much of the time spent on shop practice could probably be spent to far greater educational advantage, that many schools are still teaching far more surveying than is warranted for all but a few civil engineers, that too much laboratory teaching is of little more than manipulative value, and that the scientific analysis of experimental results leaves much to be desired. Our leadership, it must be owned, tends to be quantitative, rather than qualitative, and is due in large measure to our far richer equipment. One who examines the laboratory reports of a fourth year man in say electrical engineering at Stockholm, Delft, Berlin or Zurich, soon realizes that our students spend much industry in manipulating, observing, descriptive writing and compiling, but little on the critical analysis of the project.

Training in Management.—From the days of Taylor on American leadership in applying engineering methods to industrial organization and process has been unquestioned. In consequence our technical education reflects a wider spread of engineering activity than is common abroad, especially on the management side. The unity and freedom of our higher educational system have made it easier to introduce the economic sciences into technical education than in the compartmental systems abroad. One must credit the French, however, with special success in training engineers in the art of command due, it is claimed, to a combination of rigorous selection, high intellectual formation, professional teaching by eminent practitioners, industrial *stages*, an officer's training with the army, and—far from least—the confidence and solidarity bred of being a *Polytechnicien*.

Our curricula in industrial engineering and management are attracting wide attention abroad. Only occasionally, however, does one meet an attempt to work out the problem through a separate professional department or curriculum, as at Manchester. The Germans, who are now particularly active, are giving considerable place to both teaching and research in management matters under their regular technical faculties. Many of the same problems are met on both sides. Qualified teachers with responsible experience in management are hard to find and the revamped economist, psychologist or statistician is no nearer to the engineering ideal there than here. Teaching materials are not yet effectively organized, since management is still from being a mature and orderly science and the verdict of experience is yet to be had on the value of teaching its few generalized principles—many of them sublimated common sense—and its many detailed expedients. Higher education for business is not going any too well abroad and is far from being the rival of technical education that it is in the United States. Technical educators abroad are no clearer than we on how far to go and what methods to use in orienting the engineering student to executive and personnel problems. The Germans seem clear on one point at least, that research on the problems of selection for industrial vocations and on the laws governing the efficiency of human work, especially when coordinated with mechanical processes, properly belongs to the technical universities and requires the collaboration of engineers and psychologists. From their insistence that such research must come first and teaching follow we might learn a wholesome lesson.

Technical Research.—It is a fair generalization that in matters of technical research our institutions are far in advance of those of France and other Latin countries, on a par with Great Britain, and definitely behind Central Europe. Parity with Great Britain, however, is not an occasion for boasting, when the vastly greater scale of our university organization is considered. It is only in the last two or three decades that research has been regarded as more than an incident in the work of our engineering colleges. Our backward state, despite relatively heavy expenditures, is probably an inevitable phase of early effort. There are still relatively few men of high research capabilities in our professorial chairs; industry has requisitioned many of the most fertile for her own fast growing research establishment; and until quite recently there has been far greater incentive to text-book writing and to incidental practice than to research. Research personnel can not be improvised; that of the German institutions is the product of a century of cultivation and selection, backed up by a powerful tradition. With the fullest allowances for the difficulties of pioneering, one can not say that the matter of research has been handled by the engineering colleges in a highly statesmanlike manner. It was only rarely that the growing need was anticipated. Industry, meanwhile, having discovered the potency of research as a competitive weapon and a publicity asset, has become definitely committed to research on its own account. The policy of the colleges has been a scattering one, growing out of friendly rivalries between individuals and institutions, and less effectual than the more concentrated effort abroad. Has it been better to bring a large area under some degree of cultivation, or should we have attempted to work a few selected plots intensively? Only time can tell. At any rate, the opportunity to make the engineering colleges the chief centers of technical research seems to have passed. The Germans, whose life depends on maintaining technical pre-eminence, have little fear of the competition of our universities, but that of our industrial research laboratories is giving them serious concern.

It would seem that the development in our engineering colleges of a strong spirit of inquiry and creative effort is of much more fundamental importance than changes in the form, content or length of our curricula. Good students largely educate themselves if environmental influences are favorable. We need to be delivered from too much faith in educational routine. Pure scientific research is an indispensable adjunct to technical research, but not a substitute. One has only to consider the present situation in physics where interest is

centered almost exclusively on sub-atomic phenoma, while the molecular phenomena on which much of engineering depends are almost wholly neglected.

Status of Engineering Teachers.—This is a delicate question, but one to be faced frankly. It is a safe generalization that the engineering professor occupies a place of higher prestige and influence in each of the ten European countries which the author visited than in the United States. In the aggregate our faculties include a considerable group of engineers of the highest ability and distinction. Wide observation abroad leads almost inevitably to two basic conclusions, (1) that a large proportion of American teachers of engineering are attempting with great industry and devotion a task for which they are inadequately prepared either by scientific training, professional experience or broad personal culture; and (2) that the technical professions and industries of America have not attached great importance to placing and keeping men of the highest fertility at the chief sources of their recruitment. It is difficult, of course, to uphold standards among teachers which are much above those prevailing in the profession at large unless the major posts are invested with high prestige, wide freedom and reasonable affluence. Here Germany has succeeded in large measure, while we have scarcely envisaged the problem. Apparently we are due for a radical change in our thinking. American industry, as a whole, has been pitched to only a moderate scientific level but is now advancing rapidly. In the competition with industry for creative scientific ability teaching has steadily lost ground for nearly twenty years. Educational executives are making greater efforts to cope with the situation, but are hampered by limited funds and by the hangover of a tradition that teaching may safely be left to men of great personal devotion but of comparatively routine ability.

It is impossible to raise the level of the entire body at once. It would be almost invaluable, however, if ten or a dozen institutions could immediately be put in an outstanding position so far as salaries and qualifications of personnel are concerned. The present rise of scientific standards was not anticipated in the training of many teachers in middle life who, under our conditions of tenure, will remain in front line positions for many years to come. The immediate problem is to increase the amount and raise the level of post-graduate training in our dozen best qualified institutions; to send selected men abroad for work in special fields where we are backward—*vide* the Freeman fellows in hydraulic construction; to induce industry to send selected and tested young men from their technical staffs back to the graduate schools; to keep our most promising men free from the deadening influence of routine and to stimulate them to scientific creation rather than pot-boiling; and to pay them well enough to remove the temptation to enter industry for the sake of reasonable comfort and recognition.

On the other hand, American teachers of engineering merit a glowing tribute for their zeal in the study and improvement of the teaching process. Here the burden of world leadership clearly rests upon them, partly because of the handicaps of preparation and preliminary selection under which they labor, but more largely because American education, more than that of any other country, centers in the individual welfare of the student.

Student Life.—Wide observation at home and abroad confirms the belief that there are values worth preserving in the multifarious activities of our student life. The extreme mobility of our social system makes it essential that our youth shall have opportunity for self-discovery and personal experiment outside of the academic sphere. The large proportion of our engineering graduates who ultimately hold business and executive responsibilities is probably due in no small measure to interests discovered and abilities tried through student activities. The problem which confronts us is wholly one of proportion. The author believes it to be most unwise to load engineering undergraduates so heavily with routine and detail that a normal, healthy participation in activities is denied the average man. In these matters we have little to learn from France, Germany or elsewhere on the continent of Europe.

The English system of sport, however, is far more wholesome than our high-powered competitive athletics. America is the paradise of the self-supporting student; the attitude abroad is unfavorable to diverting so large a measure of energy from the main objectives of education. As intellectual competition grows keener in our industrial life we may have to consider whether it would not be greater economy to provide much more generously for "loans of honor" and for the payment of college fees by deferred installments or to extend much more widely the cooperative plan, than to depend so much upon casual earning power.

Integration of Academic and Practical Training.—But for the cooperative plan our record on this score would not be particularly creditable. In theory our technical professions uphold the principle that practical training is the indispensable part of an engineer's education; in practice, their attitude toward it is distinctly casual, leaving it to the individual to work out as best he can. The British and Germans particularly insist that practical training shall have form and substance as well as the scholastic curriculum. With the exception of a few conspicuous concerns in the electrical and chemical industries, our employers have followed the practice of training men for their specific needs rather than as a part of a broad professional education. The author has come to believe that the schools must take a more active and positive hand in the matter. Where the cooperative plan does not seem practicable or desirable—and this will probably remain true of a majority of our institutions—it is now time to consider how a required period of practice, under specifications which cover the character as well as the amount, may be made prerequisite for graduation.

The responsibility of the professional organizations for setting up proper codes of qualifications, to serve as guides to both scientific and practical training, needs constant urging. It is a source of weakness to our technical education that the schools, the professional bodies and the industries are not in clear agreement on the aims to be sought and the specifications to be met. It would be possible, of course, to go to the opposite extreme and fit technical education into a strait-jacket; another possibility, scarcely more attractive, would be to reduce all technical education to a process of training for specific jobs. The present danger in the colleges is all on the other side, that of a vague comprehensiveness, while the practical training in industry is too often subordinated to immediate objectives. Until the colleges have a clearer understanding of the further training which their graduates are to receive from employers, they will be in no position to deal intelligently with the amount and kind of training in engineering applications to be included in the basic college program.

The More Intensive Forms of Higher Education.—Here our record affords the sharpest contrast with that of Europe. It is impossible to claim that our present concentration of effort in degree-granting colleges represents an intelligent handling of the situation. This subject is dealt with in extended form in another report. The author therefore limits the present discussion to the bare statement of his conviction that we should erect a second educational ladder, extending through the post-secondary age levels, more strongly oriented to the higher practical pursuits of industry, intended primarily for those who have been or are collaterally engaged in active industrial pursuits, and suited to the vast number of promising young men who are not primarily book-minded but lend themselves better to more direct, practical and inductive methods of learning, such as one often finds exemplified in industry. These schools should, for the most part, give briefer and more practical programs than the colleges, base their admissions on direct evidence of ability and interest and only incidentally on formal scholastic credentials, and base their instruction as far as practicable on direct analyses of vocational usage. Suitable credentials for these educational programs, possibly similar to the National Diplomas and Certificates in Great Britain, should be developed under national auspices. The programs of these schools may well be of three general types: (1) engineering courses of fairly broad aims which parallel the university courses in more intensive fashion, but with their own distinctive teaching materials and methods; (2) courses in the technology of specific industries, such as textile manufacturing, printing, building construction, foundry practice and the like, which probably will never be largely covered in the university scheme; and (3) courses of preparation for specific technical functions, such as power plant or building superintendence, quantity surveying, textile designing, and the like. European experience, confirmed by all the available American data, indicates that schools of this character are the normal source of recruitment for many higher posts in the operating as distinct from the planning side of industry. The potential field in America for schools of these types is apparently double, or even treble, that of the professional schools of engineering.

Conclusion.—One who essays to compare forms of education with which he has long been familiar with other national forms which he must approach across barriers of tradition and often of language, under well intentioned but unconsciously biased guides, is under constant danger of setting the worst of his own nation against the best in the schemes of others. It is too much to hope that this difficulty has been fully overcome in the present study. We must not forget that we are training American youth for American life, at an age level where problems of personal adjustment are most acute. These problems are greatly accentuated by the freedom of our social order and bulk far larger in our educational scheme than in any other. Our teachers must guide as well as instruct, our students must experiment with life as well as with mechanisms. Our colleges must supply incentives from within which abroad are largely supplied through economic pressure from without. In short, our technical education will avail little if it is not thoroughly human as well as scientific.

Nor can we forget that America has left behind her an era of economic isolation. We must live increasingly in realms of world competition, where our rivals will strive to their utmost to offset our favorable position with respect to raw materials and rich home markets through the intensity of their scientific efforts. We can and will, as special needs arise, continue to import specially trained technical personnel; we dare not, however, become dependent on any external sources. Part, at least, of our technical education must be lifted to higher scientific levels.

To set before the engineering colleges some uniform, idealized scheme of curriculum and press for its universal adoption would work against progress. The problem of the curriculum is secondary and is preceded by other problems —definition of aim, selection of function, rational choice of educational process, building up an environment of creative activity, supplying incentives for superior achievement, and most of all, developing and maintaining a body of notable teachers.

The immediate need in our technical education is a rational diversification, to advance a limited part of it to definitely higher scientific and professional levels, to provide far more generous training for the higher practical pursuits of industry, and to strike a better balance between dominantly technical and dominantly managerial programs. The crux of the problem is to unite a higher concern for individual development with both a higher intellectual standard and a higher practical standard of technical preparation, ends achieved abroad through selective processes which reach to the very foundations of the social structure. The author is convinced that we will not solve this dilemma through a single, comprehensive type of school, nor by a compromise type of program. Our schools need more clearly visualized aims and programs, and a willingness to accept different but equally worthy functions in the social order.

A well proportioned national system of technical education will not grow up spontaneously. The entire situation needs to be visualized, a consistent but duly flexible policy formulated and an effective guiding and promotional effort sustained. These are joint responsibilities of educators, the organized technical professions and industry. In the absence of any national educational authority, we should strive to build up a joint representative agency of the various groups concerned—schools, colleges, professional societies, industries —and put to the test American capacity for self-government through group cooperation.