America by Design

Science, Technology, and the Rise of Corporate Capitalism

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The Wedding of Science to the Useful Arts – II

The Development of Technical Education

In the early nineteenth century the colleges were firmly in the hands of the classicists and the clerics, and there was considerable academic disdain for the study of experimental science and even more for the teaching of the "useful arts." Technical education in the United States, therefore, developed in struggle with the classical colleges, both inside and outside of them. One form of this development was the gradual growth of technological studies within the classical colleges, resulting from the reorientation of natural philosophy toward the empirical, experimental, scientific search for truth and from the pressures of some scientists and powerful industrialists for practical instruction; the other was the rise of technical colleges and institutes outside of the traditional colleges in response to the demands of internal improvement projects like canal-building, railroads, manufactures, and, eventually, science-based industry.

Again, it was Benjamin Franklin who early recognized the importance of technical education for the development of the country. As early as 1749, in a pamphlet entitled *Proposals for the Education of Youth in Pennsylvania,* Franklin called for higher educational instruction in mathematics, natural philosophy, the "mechanic powers," hydrostatics, pneumatics, surveying, navigation, architecture, optics, the chemistry of agriculture, and trade and commerce. With a few other prominent Philadelphians, he established in 1756 the Public Academy in the City of Philadelphia. The effort had meager success, however, against the forces of traditional education. In 1779 the Pennsylvania General Assembly abrogated its charter—it had fallen "under the taint of Episcopacy"—and by 1811 the practical orientation of the instruc-

tion had been diluted: science was confined to the senior year, consisting only of astronomy, natural philosophy, and the principles of chemistry and electricity; surveying and navigation were dropped altogether. Not long after this the projected King's College in New York constituted a similar attempt at practically oriented higher education. The original proposal for the college listed courses "in the Arts of numbering and measuring; of Surveying and Navigation; the knowledge of Nature . . . and everything useful for the comfort, the convenience and elegance of life, in the Manufactures relating to any of these things. . . ." But this effort also was stillborn, and Columbia College emerged along conventional lines.[1] In 1815 Count Rumford willed Harvard $1000 a year for a course of lectures to teach "the utility of the physical and mathematical sciences for the improvement of the useful arts, and for the extension of the industry, prosperity, happiness and well-being of society." The first holder of this chair was the physician Jacob Bigelow.[2]

Since the classical colleges, with their traditional elitist and religious orientation, obstructed the development of technical education in America, that education took root outside of them, at the initiative of men of affairs and in response to a popular movement for democratic schooling. Up until 1816 the number of engineers, or of men who called themselves engineers, never averaged more than two per state; the early internal improvements in the country and the planning of the national capital were directed by European engineers. But the surge of canal-building following the success of the Erie Canal created a demand for technically skilled workmen to oversee the operations, and the development of the railroad and machine industries intensified that demand. At the same time, the swelling ranks of mechanics and other skilled craftsmen who manned the industrial machine shops and railroad yards required greater access to education and science in order to develop their skills. One writer in *The Inventor* characteristically urged that mechanics be sent to the study and students to the workshop, with the theme "educate labor and set knowledge to work." In the same vein Professor J. B. Turner declared that the book learning offered by the classical colleges produced only "laborious thinkers," while what industry required was "thinking laborers."[3]

The call of mechanic and manufacturer was heeded. "I have established a school in Troy," Amos Eaton boasted in 1824, "for the purpose of instructing persons . . . in the application of science to the common purposes of life."[4] Eaton, an applied scientist with a Baconian spirit who studied chemistry with Benjamin Silliman at Yale, joined with

Stephen van Rensselaer, a wealthy landowner and capitalist, to start the Rensselaer School in 1823. In 1849 the school was reorganized by B. Franklin Green, after a careful study of technical education in Europe, along the lines of the Ecole Centrale des Arts et Manufactures. Renamed the Rensselaer Polytechnic Institute, it signaled the ascendancy of professional training for engineers in America. At the same time, the U.S. Military Academy at West Point, which had incorporated applied-science instruction in the curriculum under the direction of Superintendent Sylvanus Thayer, had begun to produce civil engineers with training in chemistry, physics, and higher mathematics as well as practical engineering.

The success of these pioneering efforts outside of the established colleges had its effect on them, at first with the inclusion of experimental science and later with the incorporation of practical studies in the curriculum. This effect was reflected in the fact that such outstanding physical scientists of the nineteenth century as Joseph Henry, Alexander Bache, the founder of the Franklin Institute, Henry Rowland, and J. Willard Gibbs had all been trained originally as engineers. Similarly, it was an RPI graduate, the chemist Eben Horsford, who persuaded the New England mill owner Abbott Lawrence to give Harvard funds for scientific studies. With a grant of $50,000 to underwrite the operation of the new Lawrence Scientific School, Lawrence specified that he wanted an institution in which scientific education was to be applied to engineering, mining, metallurgy, and the invention and manufacturing of machinery. "Where can we send those who intend to devote themselves to the practical applications of science?" Lawrence wrote the treasurer of Harvard in 1847. "How educate our engineers, our miners, machinists and mechanics? We need a school for young men . . . who intend to enter upon an active life as engineers or chemists or as men of science, applying their attainments to practical purposes." In addition to the purely technical aspects of such training, Lawrence foresaw the need for management training. "Hard hands are ready to work upon materials," he wrote, "and where shall sagacious heads be taught to direct those hands?"[5] Despite the explicit intention of Lawrence, however, the directors of Harvard took only a half-step toward practical instruction; Louis Agassiz, the noted geologist and zoologist, received most of the funds. Not until 1854 did the first engineer graduate from Harvard, and by 1892 there had been only 155. Harvard's reluctance to realize Lawrence's intentions was an important factor contributing to the establishment of the Massachusetts Institute of Technology in 1861.

Founded by the geologist William Barton Rogers and like-minded scientific and civic leaders of Boston, MIT embarked upon a broad range of scientific and technical instruction. Its purpose was its motto: *Mens et Manus.* Interestingly, the name "Technology" was proposed by Jacob Bigelow, one of the new school's supporters, to indicate that the study of science at MIT, rather than being a form of polite learning, would be directed toward practical ends. The MIT school of industrial science opened in 1865, and within a decade individual laboratory instruction in the physical sciences had been introduced as the focus of engineering education; science, as Benjamin Franklin had foreseen, had indeed become handmaiden to the arts.

At Yale the efforts to establish applied scientific study were more fruitful than at Harvard. In 1846 the Yale corporation reluctantly allowed two professors, John P. Norton and Benjamin Silliman, to establish extension courses to teach agricultural chemistry and other practical subjects, largely in response to the pressure of Norton's father, a powerful alumnus of the college. Until 1860 the enterprise was housed in the chapel attic and relied exclusively upon fees for support. In that year Joseph E. Sheffield endowed the venture, thereby creating the Sheffield Scientific School. It was in this school that the first Ph.D. in chemistry in the United States was granted and the first course in mechanical engineering was begun.[6]

While Yale and Harvard attracted the largest contributions for their scientific and technical work, other colleges had also begun to offer such courses. Union College established its civil-engineering course in 1845, followed by Brown two years later, and Dartmouth formed the Chandler Scientific School in 1851. The University of Michigan commenced instruction in engineering in 1852, under the direction of Brown graduate DeVolson Wood, and Cornell set up the Sibley College of Engineering in 1868. Within a decade Robert Thurston had moved from Stevens Institute to Cornell and had introduced laboratory instruction in physical science there. By the late 1870s, after scientific research in chemistry had begun in earnest at Johns Hopkins, courses in "industrial chemistry" or "chemical technology" were undertaken at various colleges.[7] At Columbia, Charles F. Chandler introduced applied-chemistry courses and founded the School of Mines; similar instruction was introduced by Samuel P. Sadtler at the University of Pennsylvania; by Edward Hart at Lafayette College; by William McMurtie and S. W. Parr at the University of Illinois; by A. B. Prescott and E. D. Campbell at the University of Michigan; and by Willis Whitney and A. A. Noyes at MIT.

Without doubt, the big leap forward in technical education in America came in 1862 when Congress passed the Morrill Act granting federal aid to the states for the support of colleges of agriculture and the mechanic arts. State legislatures that had been deaf to all appeals for technical instruction now quickly accepted the federal grants and voted to create the new type of school, while established colleges caught the spirit and added departments of engineering. In the first decade following the passage of the Morrill Act, the number of engineering schools jumped from six to seventy. By 1880 there were eighty-five, and by 1917 there were 126 engineering schools of college grade in the United States. Between 1870 and the outbreak of the First World War, the annual number of graduates from engineering colleges grew from 100 to 4300; the relative number of engineers in the whole population had multiplied fifteenfold.[8]

With the wedding of science to the useful arts, the former became more empirical and then practical while the latter became more scientific. Empiricism was introduced into scientific study as a means of understanding metaphysical truths, a guide to reflection. In the late nineteenth century, however, this process underwent a subtle inversion whereby practical experience, the handmaiden of science in the search for truth, made science its own handmaiden. Mansfield Merriman, president of the infant Society for the Promotion of Engineering Education, described in his presidential address of 1896 how this came about. "First, the principles of science were regarded as principles of truth whose study was ennobling because it attempted to solve the mystery of the universe; and second, the laws of the forces of nature were recognized as important to be understood in order to advance the prosperity and happiness of man. The former point of view led to the introduction of experimental work, it being recognized that the truth of nature's laws could be verified by experience alone; the latter point of view led to the application of these laws in industrial and technical experimentation."[9]

The first view of science led to a progressive relaxation of opposition to science in the classical colleges, on the grounds that empirical investigations were an aid to metaphysical speculation, but opposition to the second view, that science had practical implications, continued unabated. Thus, when Ira Remsen went to teach chemistry at Williams College and requested funds for laboratory facilities like those in German universities, he was met with a telling response: "You will please keep in mind," the school officials admonished him, "that this is a

college and not a technical school. The students who come here are not to be trained as chemists or geologists or physicists. They are to be taught the great fundamental truths of all sciences. The object aimed at is culture, not practical knowledge."[10]

But science had gained a foothold. By 1895 Palmer Ricketts, director of RPI, could reflect in hindsight that "the youngest of us here remembers how many of the academic schools were unwillingly forced to add scientific departments in compliance with public demand," and DeVolson Wood of Michigan could allude to the "favorable auspices" for the annual meeting of the Society for the Promotion of Engineering Education in 1894, "because the antagonisms of the past between classical education and scientific education have passed away." Indeed, by the turn of the century a growing number of American colleges were awarding Ph.D.'s in the sciences and could already claim a number of distinguished physical scientists, men such as A. A. Michelson, Simon Newcomb, Henry Rowland, T. W. Richards, J. Willard Gibbs, George Ellery Hale, R. W. Wood, S. P. Langley, and Ira Remsen. At the same time, however, those who pursued a more practical approach to scientific study were not so readily welcomed in academe, a fact which preoccupied these engineering educators. The applied scientists in the engineering departments continued to occupy a second-class status within the academy, and, ironically, the scientists with their newly won respectability often enough lined up with the classicists against the technical educators across the campus.[11]

Their apparent inferior position galled and intimidated the engineers. Samuel Warren of RPI labeled the classicists a "crew of disreputable divinities," and President Francis Amasa Walker of MIT railed against them as he insisted upon the superiority of technical training. "Too long have we submitted to be considered as furnishing something which is, indeed, more immediately and practically useful than the so-called liberal education, but which is, after all, less noble and fine. Too long have our schools of applied science and technology been regarded as affording an inferior substitute for classical colleges. Too long have the graduates of such schools been spoken of as though they had acquired the arts of livelihood at some sacrifice of mental development, intellectual culture, and grace of life. . . . I believe that in the schools of applied science and technology is to be found the perfection of education for young men."[12]

For engineering educators within the liberal arts colleges, men who had to deal with their inferior status on a daily basis, such strength of conviction was hard to come by. More often, the condescension of the humanists and scientists led to self-recrimination and doubt. E. A. Fuertes, civil-engineering professor at Cornell, lamented that "the reason why our profession suffers in the way of which we complain is because it is not like the French body of engineers, which is composed of men who are *ipso facto* cultured gentlemen of great social power. The reason why we have not yet such powers is because we do not deserve it; there cannot be any other reason; it is the only reason that could exist."[13] For the engineering educators, second-class status within the academy was unbearable, and their preoccupation with it made it a topic of discussion at every meeting of the SPEE. For many, however, the solution to the problem was obvious: they must either increase the scientific content of their courses, in order to capitalize on the growing respectability of science, or increase their offerings in "culture studies." They did both.

From about 1870 on, the engineering curricula became distinctly more scientific and the focus of scientific study was shifted from laws of nature to principles of design. This tendency reflected both the engineering educators' quest for academic respectability and the increasing complexity of engineering problems, which defied the traditional cut-and-try approach. Most early instruction in the engineering departments and technical schools had placed great emphasis upon practicality, the *raison d'être* of engineering, in opposition to the "useless" cultural fare of the classical colleges. Such instruction was marked by liberal amounts of shop work, especially at such schools as Worcester and Cornell, and exercises in the drafting room and the field, with only occasional demonstrations by science instructors. After 1870, however, there was a slow but decided trend toward the use of laboratory methods of scientific investigation and experimentation in the solution of engineering problems, and engineering schools gradually undertook construction of laboratory facilities. In civil engineering, for example, there was a new emphasis upon mathematics and physical theory in design, and construction and mining engineers came to rely upon the fundamentals of chemistry. In mechanical engineering also, under the influence of science-minded engineers like Robert Thurston, instruction came increasingly to be based upon the scientific principles of hydraulics, thermodynamics, and the strength of materials, subjects which were often classed as branches of physics.[14]

This trend toward scientific engineering was most pronounced, of course, in the newer branches of engineering which accompanied the rise of science-based industry: electrical and chemical engineering. Instruction in these fields was as much the product of the departments

of physics and chemistry as it was an offshoot of mechanical engineering, and the first teachers were men who had been trained as chemists and physicists. The first electrical-engineering courses were offered in the 1880s at universities like Wisconsin, Cornell, and MIT; "industrial chemists" were trained in the late 1880s and 1890s at Wisconsin, Michigan, and MIT, but instruction in chemical engineering proper, based upon the concept of unit operations, did not begin until MIT launched its School of Chemical Engineering Practice in 1917. In both of these fields the evolution was from the scientific toward the technical, rather than the reverse as in the other branches of engineering, and so instruction was grounded upon scientific theory from the outset. Moreover, as William Wickenden later observed, "this increasing scientific emphasis was greatly advanced by the close bond between the schools and the newer industries which had developed directly out of scientific research and technique, notably the electrical industry. An understanding arose, almost from the beginnings of the industry, under which the employers assumed practically the entire responsibility for the practical training of the student and the college was left to devote itself to the scientific foundations."[15]

This trend toward science and mathematics in the engineering curricula raised as many problems as it solved, however. At the turn of the century the great majority of practicing engineers were still those who had received their training in the "school of experience" rather than in the colleges of engineering. There were in fact, as Monte Calvert has described, a distinct traditional "shop culture" in mechanical engineering and a "field culture" in civil engineering which were very much in conflict with the newer "school culture" of the younger engineers. The increasingly scientific nature of the college training added to this tension. Engineers of the "rule-of-thumb," "cut-and-try" method resented the pretensions of the younger, scientifically oriented, "hypothetical" engineers, who invariably worked under them before rising into managerial positions. "Time was," remarked Ashbel Welch before an 1876 joint meeting of the new American Society of Civil Engineers and the American Institute of Mining and Metallurgical Engineers, "there was some truth in the saying, that the stability of a structure was inversely as the science of the builder." Such sentiments had hardly died out among practicing engineers; indeed, many of them continued to hold this view well into the twentieth century even as the school culture began to dominate the profession. William Burr, for example, reported in 1894 that "many men engaged in practical duties of an engineering nature frequently, and perhaps usually, complain that . . . young engineers almost invariably have failed to possess" the capacity to deal effectively with practical problems.[16]

The experience-trained engineers were in a very powerful position vis-à-vis the schools of engineering, since it was they, and not the college-trained engineers, who dominated the industries which employed the graduates. Finding the graduates ill-equipped to handle the routine problems of industry, these practicing engineers put considerable pressure upon the schools to adapt their curricula to meet the demands of the "real world." By the close of the century their impact was reflected in the frantic attempts by the schools to provide shop training for their students, alongside the courses of scientific principles and whatever "cultural" courses there were.[17]

The conflicting demands of engineering educators for academic respectability, of a growing profession for esoteric knowledge, and of employers for practically trained men placed a great strain upon the educators, many of whom were also practicing engineers and regarded themselves as professionals. Not surprisingly, their overriding concern during the last decade of the century was that of trying to meet all the requirements of their calling within the standard four-year curriculum. As the embodiment of the wedding of science to the useful arts, the engineer reflected also the tensions inherent in that marriage. William Burr of Columbia College tried to reconcile the work of the shop with that of the laboratory, by emphasizing the scientific importance of the former and the practical importance of the latter. The demands for scientific training, he assured the practical men, "are not the opinions of theorists nor the erratic and irresponsible utterances of impractical men. . . ." The "ideal engineering education," he argued, "consists of a most thorough training in mathematics and physics, but adapted in its entire matter and method to the subsequent engineering practice." However, while "the mechanical engineering student must [therefore] take a comparative large amount of workshop practice, it must be for the training of a mechanical engineer and not for the purpose of attaining the skill of a mechanic."[18]

The efforts of the engineering educators to meet the demands of their profession, academic status, and employers of engineers were never wholly satisfactory. Indeed, the problems have remained the focus of their concern throughout the twentieth century. By the end of the nineteenth century the schools lagged seriously behind the rapidly changing needs of the science-based industries. Even in the larger institutions like Yale, Michigan, Wisconsin, MIT, and Purdue, where adequate shop facilities were available for training in "real world"

techniques, the equipment quickly became obsolescent with advances in industry. To fill the gap between formal education and the requirements of employment, therefore, major industrial concerns established in-house training programs, the more or less elaborate "corporation schools." The R. Hoe Publishing Company was the first to do so, in 1875, and the electrical industry followed suit on a large scale shortly thereafter. By the turn of the century such training programs were provided in many large companies. The electrical industry had perhaps the largest of these, and American electrical-engineering graduates normally went to the "test course" or "special apprentice courses" at Lynn, Schenectady, Pittsburgh, or Chicago to complete their education before embarking upon professional careers. At GE, as at the other companies, "the test course was a path between college and business." The corporation-school idea spread considerably between 1890 and 1915; by the second decade of the century, however, new far-reaching approaches toward "education-industry cooperation" were being formulated to bridge the gap between the classroom and the workplace, between scientific theory and engineering practice.[19]

The problems presented by the strictly scientific and technical aspects of engineering education were compounded, in the closing decades of the nineteenth century, by others involving the proper role of the "cultural courses" in the education of engineers. Engineering educators sought to determine the proper relationship between such courses as history, literature, rhetoric, political economy, moral philosophy, and languages—which they ambiguously labeled "humanities" or "culture studies"—and the purely technical instruction, a relationship which would meet the requirements of professionalism, academic status, and engineering practice. Since the first technical schools arose in opposition to the classical colleges, they initially refused to offer any "culture studies" at all. Amos Eaton of RPI had nothing but scorn for the established colleges; the RPI brochure of 1826 boasted that the school "promises nothing but experimental science. . . . Its object is single and unique; and nothing is taught at the school but those branches which have a direct application to the 'business of living.' "[20] However, while the technical institutes, such as Worcester, tended to follow this path, the new schools of engineering adopted a more relaxed posture toward their "adversaries" in the classical colleges. MIT and Cornell, for example, pioneered in establishing "humanities" courses for engineering students which ran concurrently with the technical curriculum. When the classical colleges eventually established their own engineering schools, these adopted a similar pattern of concurrent instruction, as did the majority of engineering schools thereafter; in time even RPI followed suit. The Morrill Act also adopted this approach to technical education; it specified that the new land-grant schools "shall be, without excluding other scientific and classical studies . . . to teach such branches of learning as are related to agriculture and the mechanic arts . . . in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life."[21]

The concurrent curriculum, however, though widely adopted, did not altogether eliminate the antagonism between the "business of living" and "culture" or the debates over the training required for each. While some engineering educators, seeking to enhance their professional prestige, tried to emulate the refined airs of the liberal-arts professors, others attacked such pretensions as elitist and vacuous. "[A] broad cultivation," one professor argued, "is the only effectual corrective for the narrow and malformed excellence in some special direction, which falls lamentably short of the vigorous and well-rounded product of the ideal education in engineering. . . . The first and fundamental requisite in the ideal education of young engineers," he added forcefully, "[must be] a broad, liberal education in philosophy and the arts." An anecdote offered by Professor Robert Thurston, on the other hand, suggested a contrary view. Scorning the inclusion of culture studies in the engineering curriculum, he reflected that "the most singular mixtures of literature, history, and other non-professional studies with engineering were often prescribed, as where, in one now famous institution of learning, 'biblical exegesis' constituted a portion of the regular course in civil engineering, or whereas, in the early days of Cornell University, Roman history was similarly imbedded in a course nominally . . . in civil engineering 'like a flyspeck on a white wall,' as the finally emancipated head of the department was heard to say."[22]

There was thus considerable debate in the 1890s among engineering educators about the future of the concurrent curriculum. Henry Eddy concluded that as "the two kinds of study interfere with each other . . . it seems clear that the culture studies must soon disappear from our engineering courses." President Walker of MIT, an economist, strongly disagreed. He predicted that "doubtless more of the economic, historical, and philosophical studies will be introduced, to supplement, by their liberalizing tendencies, the work of the sciences in making the pupils exact and strong. Possibly, some ultimate form for institutions

of higher learning may yet be developed, which shall embody much of both the modern school of technology and the old-fashioned college."[23]

This debate sustained within the engineering schools the same antagonism as had existed originally between the technical schools and the classical colleges. Engineering educators wanted to enhance their professional and academic prestige by means of a broadened "liberal" education for the engineer, and at the same time to maintain their role as "real world" revolutionaries within the academy. Their debates reflected this ambivalence. By the turn of the century, however, a number of farsighted engineering educators began to recognize distinctions within that realm which they loosely called "culture studies" or "humanities," distinctions which prompted a reevaluation of their usefulness. While Walker, for example, lumped together "economic, historical, and philosophical studies," a former SPEE president told engineering educators that he had recently become "impressed with the great importance of some other subjects . . . which are not taught in our schools of engineering but which are taught in other departments of our large universities, subjects which in general are under the term humanities. . . . Some of these subjects are becoming real sciences," he pointed out, "and not simply formulated theories and opinions, and the engineering students ought to know something about them."[24]

The emergence of the social sciences—economics, political science, psychology, and sociology—led some engineering educators to redefine the role of "culture studies" in the engineering curriculum. They began to see that some non-engineering courses could have practical value in addition to mere status value—that, rather than simply making the students more refined and "cultured" gentlemen, they could make them more effective engineers. Stressing the importance of knowledge in the social sciences at a time when increasing competition, expanding plants and markets, and intensifying labor conflict were raising difficult problems for the managers of industry, Mansfield Merriman suggested that "the main line of improvement to secure better results will be . . . in partially abandoning the idea of culture and placing the instruction on a more utilitarian basis." William Burr similarly voiced the growing sentiment of practicing engineers in industry when he argued that "engineering education must enable engineers to meet men as well as matter." As more and more engineers worked their way up into the managerial positions of corporations, particularly within the electrical and chemical industries, they began to find fault with the training they had received, training which had not prepared them for the challenges of corporate management. Roughly two-thirds of all engineering graduates were becoming managers in industry within fifteen years after graduation, and they increasingly put pressure on the engineering schools to provide training for all aspects of an engineering career rather than the merely technical. As a result, while the more traditional offerings of the "cultural studies" curriculum—languages, Bible study, ancient history, moral philosophy, and rhetoric—were gradually phased out of engineering programs, new subjects labeled "humanities" and later the "humanistic-social stem"—political science, economics, psychology, sociology—were introduced. While some engineering educators continued to try to broaden the curriculum in order to enhance their academic and professional prestige, others, at the behest of the managers in the new science-based corporations, began to call for a "liberal" education for other reasons. As one engineer phrased it, "A liberal education gives power over men."[25]

3

The Wedding of Science to the Useful Arts – III

The Emergence of the Professional Engineer

In the eighteenth century, and to a lesser extent up through the middle of the nineteenth, contact between the separate realms of science and manufactures was limited to the personal association of upper-class gentlemen with feet in both worlds. By mid-century, however, with the gradual reorientation and increasing popularization of science, such contact, while remaining haphazard, became more common outside the elite circles, and the chance adaptation of scientific methods and discoveries to the practical ends of commercial enterprise eventually gave rise to both science-based industry and schools of scientific technology.[1] In addition, a new social type emerged to personify this union: the engineer. "Science and invention were joining hands; their lusty issue was Engineering."[2] The engineer in America, the legitimate child of the epochal wedding of science to the useful arts, was the human medium through which it would work its profound social transformation. He was, as engineers themselves tirelessly boasted, a new breed of man, the link between "the monastery of science and the secular world of business," whose calling, engineering, bridged "the gulf between the impersonal exact sciences and the more human and personal affairs of economics and sociology."[3] By the end of the nineteenth century the province of engineering—modern technology—had already attracted "the brightest and most gifted men."[4] Many of those ambitious and fortunate young men who would formerly have devoted themselves to religion, politics, philosophy, or art turned instead to explore, map out, and lay claim to this vast new realm of human enterprise.

Modern technology, as the mode of production specific to advanced industrial capitalism, was both a product and a medium of capitalist

5. Herbert Marcuse, "Some Social Implications of Modern Technology," *Studies in Philosophy and Social Science*, IX (1941), 414.
6. Marcuse, *One-Dimensional Man*, p. 32.
7. Karl Marx, *Capital* (Chicago: Charles H. Kerr and Co., 1926), I, 397.
   Marcuse, "Some Social Implications of Modern Technology," p. 424.

Chapter 1

1. Benjamin Franklin, quoted in Hugo Meier, "The Technological Concept in American Social History," unpublished Ph.D. dissertation, University of Wisconsin, 1950, p. 347.
   Jacob Bigelow, *Elements of Technology* (Boston: Boston Press, 1829), pp. iii–v.
2. For some further discussion of the origins of scientific technology, see Peter F. Drucker, "The Technological Revolution," *Technology and Culture*, II, 342–9; Lewis Mumford, "Technics and the Nature of Man," *Technology and Culture*, VII, 303; Lynn White, "The Historical Roots of Our Ecological Crisis," *Science*, CLV (March 1967), 1203; Daniel Horowitz, "Insight into Industrialization: American Conceptions of Economic Development and Mechanization, 1865–1910," unpublished Ph.D. dissertation, Harvard University, 1966, p. 52; and George H. Daniels, *Science in America* (New York: Alfred A. Knopf, 1971), p. 271.
3. Karl Marx, *The Grundrisse*, translated by David McLellan (New York: Harper and Row, 1971), p. 140.
4. Harry Braverman, *Labor and Monopoly Capital* (New York: Monthly Review Press, 1974), p. 166.
5. Annual Report quoted in Harold C. Passer, *The Electrical Manufacturers* (Cambridge: Harvard University Press, 1953), p. 54.
6. Edison quoted in Philip Alger, *The Human Side of Engineering* (Schenectady: Mohawk Development Service, 1972), p. 18.
   Thomas P. Hughes, "The Electrification of America, 1870–1930," address delivered at the Bicentennial Convention of the Society for the History of Technology, Washington, D.C., October 18, 1975.
   Passer, *Electrical Manufacturers*, p. 177.
7. Passer, *Electrical Manufacturers*, p. 85.
8. *Ibid.*, pp. 325, 104. "Frederick P. Fish," in *National Cyclopaedia of American Biography*, XXVI, 202; XXXIX, 278. *Proceedings of the Bar Association of the City of Boston and of the District Court of the United States for the District of Massachusetts, "In Memory of Frederick P. Fish, Boston, Massachusetts, December 26, 1931,"* p. 4, Massachusetts Historical Society, Boston. See also Edward C. Kirkland, *Industry Comes of Age* (New York: Holt, Rinehart and Winston, 1961), pp. 191–2.
9. Passer, *Electrical Manufacturers*, pp. 129–76.
10. Malcolm MacLaren, *The Rise of the Electrical Industry During the Nineteenth Century* (Princeton: Princeton University Press, 1943), pp. 105–6.
11. N. R. Danielian, *AT&T: The Story of Industrial Conquest* (New York: Vanguard Press, 1939), p. 94 and Chapter 5. See also Horace Coon, *American Tel & Tel: The Story of a Great Monopoly* (New York: Longmans, Green & Co., 1939), pp. 31–93.

12. Theodore N. Vail, quoted in Danielian, *AT&T*, p. 95.
    Frederick P. Fish, "The Patent System," *Transactions of the American Institute of Electrical Engineers*, 1909, p. 335.
13. Gabriel Kolko, *The Triumph of Conservatism* (New York: Free Press, 1963), p. 47.
14. The following discussion of the rise of chemical manufactures in the United States is based primarily upon Williams Haynes' six-volume *American Chemical Industry—A History* (New York: D. Van Nostrand Co., 1954); Williams Haynes and Edward L. Gordy, eds., *Chemical Industry's Contribution to the Nation, 1635–1935*, Supplement to *Chemical Industries*, 1935; *The Chemical Industry Facts Book* (New York: Manufacturing Chemists Association, 1953); Don Whitehead, *The Dow Story* (New York: McGraw-Hill, 1968); and William S. Dutton, *Du Pont* (New York: Charles Scribner's Sons, 1949).
15. Herstein's study, cited by Haynes, *American Chemical Industry*, III, 411.
16. Haynes, *American Chemical Industry*, III, 409. See also Haynes and Gordy, eds., *Chemical Industry's Contribution to the Nation*.
17. Haynes, *American Chemical Industry*, IV, 33.
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