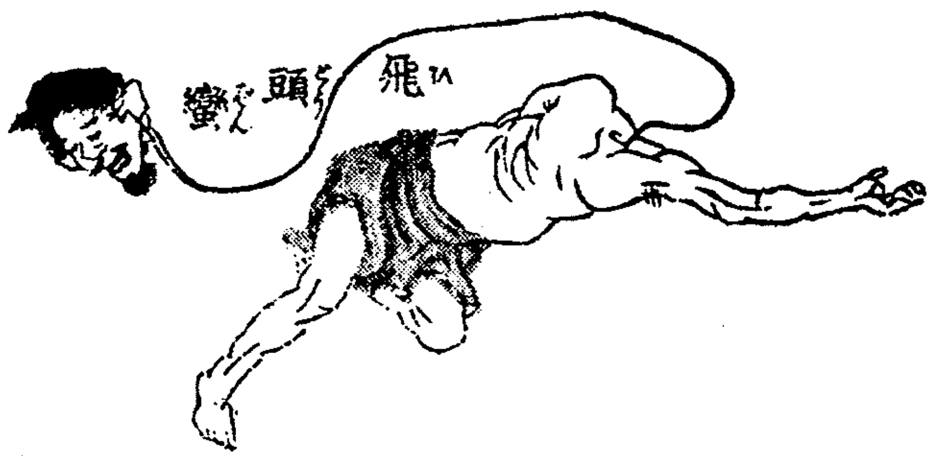
The University Community; Teaching and Research; Opportunities and the Road to Greatness



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M. PASTEUR.

In front of the Pasteur Institute, in Paris, is a bronze statue of a French shepherd boy engaged in a death struggle with a mad dog which had been worrying his sheep. With his bare hands, and with no weapon save his wooden sabot, the boy killed the dog, but was horribly bitten in the fight, and this statue represents an actual struggle which took place in October, 1885. The event gave the now famous French savant his first prominent opportunity of experimenting with his anti-rabic treatment upon a human being. The treatment was successful, and from that time to this many thousands of persons who have been bitten by rabid animals, of all countries and all stations in life, have been visitors to Pasteur's laboratory, to receive such treatment as would insure them, so far as human science could do so, against a horrible death. The French nation raised a monument to the discoverer of this antirabic treatment in the shape of the "Pasteur Institute," and there are now many similar institutions in various parts of the world, including one in New York City. Pasteur commenced his researches on rabies and hydrophobia in 1880 when little was known of the disease except that the virus was contained in the dog's saliva. He first proved by experiment that the disease was one localized in the nerve centers, finding that a portion of the matter of the spinal column of a rabid dog, when injected into a healthy one, causes rabies much more certainly and rapidly than does the injection of the saliva. This also explains the varying times of attack of the disease after a bite, the virus having to travel up the spinal cord before the symptoms can manifest themselves. The next problem was to weaken the virus, which proved a difficult and somewhat complicated task, as previous attempts to cultivate the special microbe of rabies outside the animal body had failed. But Pasteur's perseverance and method overcame the difficulty, and he succeeded in so far weakening the poison that in his hands it lost its virulent effects, while yet remaining potent enough to act as a preventive, so that dogs inoculated with this weakened virus might be bitten with impunity by mad dogs.

The Pasteur treatment has been virulently attacked because it has not always been successful; but this is something which has never been claimed for vaccination for any form of disease. It is estimated that from fifteen to twenty persons out of every hundred bitten by mad dogs or cats develop hydrophobia, but in 9,164 persons treated at the Pasteur Institute to January, 1889, there was a mortality of only 1.4 per cent, while in 1887 the mortality was reduced to 1.3 per cent, and in 1888 to 1.16 per cent. As touching this point, Sir Henry Roscoe says: "Pasteur's treatment is really a race between a strong and an attenuated virus. In cases in which the bite occurs near a nerve center, the fatal malady may outstrip the treatment in the race between life and death. If the weakened virus can act in time, it means life; if the strong virus acts first, prevention comes too late, and it means death. So that the treatment is not doubtful in all cases, but only in those which are under well known unfavorable conditions."

But it is not alone for his successful treatment and prevention of hydrophobia that M. Pasteur is entitled to a high place among the scientists and benefactors of the age. In 1857 he inaugurated researches on the action of the mould in the changes it effects on tartaric acid and the process of fermentation, which pointed the way to scientific improvements in brewing and wine making of the greatest value, and were said to be the stepping stones of the present science of bacteriology. He proved that the changes occurring in each of the various processes of fermentation are due to the presence and growth of a minute organism, that every peculiar fermentative change is accompanied by the presence of a special ferment, and this he proved by the most careful experimental inquiry, joined with the artificial cultivation of these organisms. In a visit to a large London brewery, in 1871, he explained by the use of a microscope the cause of a serious state of

M. PASTEUR IN HIS CABINET AT THE PASTEUR INSTITUTE, PARIS.

The University Community; Teaching and Research; Opportunities and the Road to Greatness

Speech presented*
5 June 1999

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*Oral Presentation an abridged version of this text.

Mr. President, Ladies and Gentlemen, Colleagues

Happy Birthday to Kobe University, to the Faculty of Kobe University, to the students of Kobe University, to the staff of Kobe University and to the Alumni – those who have graduated from this University and gone forward into the world to new adventures and to make their contributions to society.

It is a privilege for me to participate in this ceremony. I have great respect for both Kobe University and for the city of Kobe who have bravely rebuilt their dynamic communities after suffering the disaster of a great earthquake. All of us at Caltech who also live in earthquake country recognize the risks, the courage, and the accomplishments. Today, I have been asked to speak on a subject in which I have no competence. I am just a professor with some experience, many opinions, and no authority. I considered this invitation to speak a challenge that should be accepted. What will be reported here is thus full of uncertainties and errors of fact and opinion.[1]

For a human being, a person, an individual – the 50th birthday celebration is a special event. It represents the full age of maturity when more than one-half of your life is past, your capabilities and potential have been defined, some of your achievements may have been recognized and when you set out on a path

[1] I have used many sources in preparing this report and have profited greatly from their study. These more serious investigations are not cited or documented due to my time limitations. I hope this unscholarly approach is forgiven in this rather personal attempt to review some history.

to those goals that you believe may fulfill your existence. For an institution, a Fiftieth Anniversary has a very different meaning. Institutions are social structures that fulfill some needs of society. As such they have a time scale for performance that greatly exceeds an individual's life span and they often endure long after some of the transitory structures of a society have greatly changed or even disappeared. Universities are such institutions. Some have been in existence for over 800 years – through Emperors, Kings, Queens, high priests, churches, religious cults, Supreme Councils and Republics. The age of a university may contribute to its apparent dignity, but its true dignity lies in its ability to educate and to train for greatness. Universities are a route to facilitate access to society's rewards. They must also participate in defining societies, training individuals for advances both social and occupational. Universities must provide society as a whole with a cadre of people who have some understanding of the world and some broad vision of the world [see Figures 1 and 2]. The educational and research goals of a university require self-renewal. There can be no fixed and unaltered programs for education. The whole process must be regularly re-evaluated, and changed to seek effective directions of scientific research, technical innovation and intellectual illumination. Though the universities may aid in training individuals so that they will have "iron rice bowls" – guarantees of some sort of stable existence for alumni, their deeper purpose is the cultivation of greatness that is hidden in individuals [see Figure 3]. In the following I will try to present to you a pocket history of universities and my views on the current and future problems which face them. My emphasis will be on American schools. However, I must first express my view of universities.

Figure 1. Part of a university education is to teach the students some basic techniques and approaches to known problems.

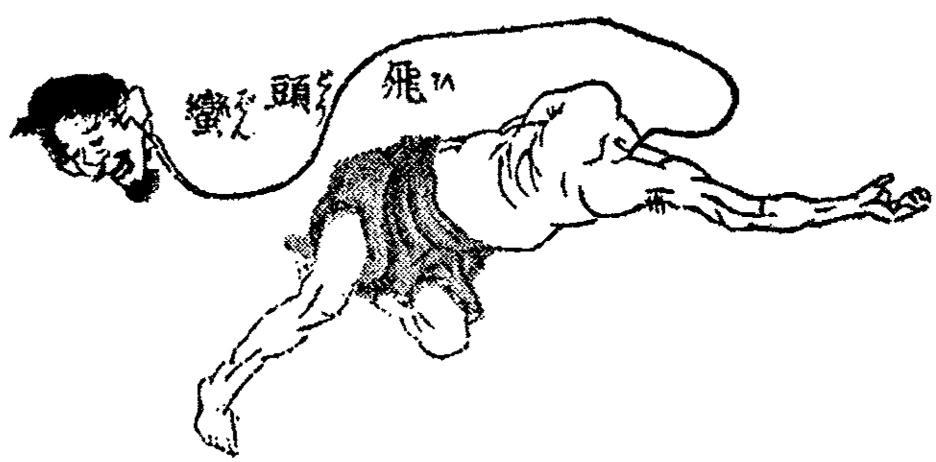


Figure 2. The other part of a university education is to stimulate the imagination and creativity of young scholars to identify new problems, but with some attachment to reality.

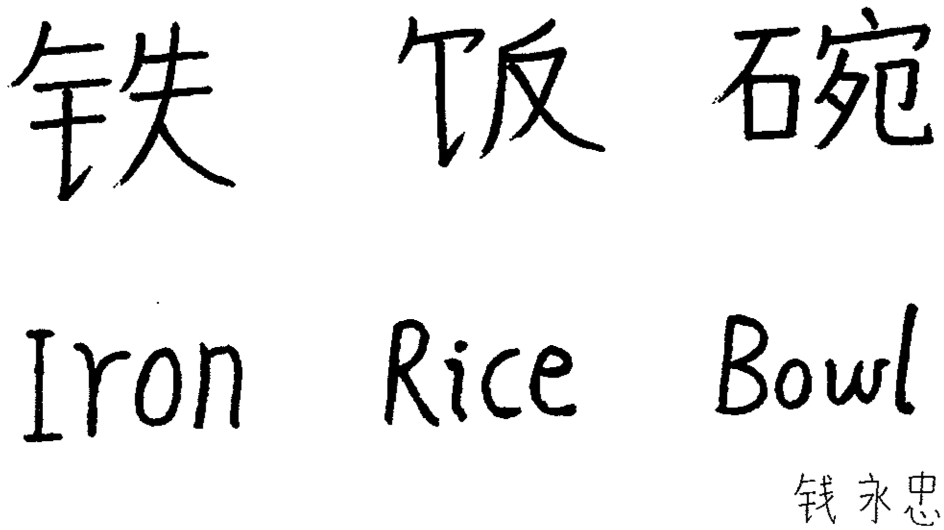


Figure 3. Chinese aphorism for a job or position which guarantees for life a steady income. Calligraphy courtesy of Yong-Zhong Qian.

I believe that a university is like the small grain of sand embedded in the flesh of an oyster. It is an irritant and a stimulus that can, under the proper conditions, cause the oyster to produce a precious pearl which greatly enhances the beauty and value of the oyster.

In considering the current state of universities – teaching, scholarship, research and contributions to society, it is interesting to look back over the history of universities. Human society both needs and cherishes universities and research institutions. Society has supported them, strengthened them, and tried to control them. Attempts have been made to drive out dissent and the dissidents. Universities have then been renewed and reformed to include the new views previously rejected, sometimes violently. In addition to universities, society has sought other mechanisms (e.g. federal and industrial research centers) to provide the knowledge and research that it believes are needed.

In the past most "scholars" in the western world were tutors in the service of princes or instructors in the service of some religious sect. They supported themselves by the payment of fees for their services. When much was lost in the western world during the Dark Ages, the religious orders were the seat of reading and writing and knowledge (some of it practical) which they passed on to succeeding generations of clergy [see Figure 4]. The universities, when they were founded, were agents of the Emperor and of the State church. Instruction was mostly directed toward training people (mostly men of course) in law, medicine, philosophy and, naturally, the "ancient" languages of Latin, Greek and Hebrew [see Figure 5]. The students were almost exclusively from well-born or wealthy families [see Figure 6]. Membership in the University (both for faculty and students) was usually related to acceptance of state authority and the state religion. Ferment and change in the Universities were most usually associated with social changes – often revolutionary – such as the overthrow of churches and of kings. At the least, the changes were symptomatic of, or in support of, major social and economic changes.

The very early universities were the University of Bologna, Italy (1088), Paris, France (1215), Oxford (1096-1231), and Cambridge (1296). In the late 1300s there was a blossoming of universities, Carolina (1348, Prague), Vienna (1365), Köln (1388), Heidelberg (1386) etc. These institutions were less concerned with the education of students and more concerned with the study by experts in law, theology and medicine for their respective courts. They were all organs of the state and of the state religion.

A major technical revolution took place in 1454 in Mainz, Germany. Johann Gensfleisch Gutenberg set up typography – printing with movable resettable type. Printing opened up a whole new world of communication which, within thirty years, spread

Figure 4. A teaching scene showing the young monks and the students from the early 14th century (from Peter Moraw). Note the teacher is large and the students are small.

Figure 5. Presentation of a Ph.D. at Heidelberg in the 16th century (from Peter Moraw).

throughout the western world. It was to remake both information transfer and universities, leading to the rapid exchange of ideas. (In the latter part of this century, we too are undergoing a new technical revolution in rapid and widespread communication which will have an even greater and hopefully better effect.)

Figure 6. Rector, Professor, and student in Basel, Switzerland in the early 17th century (from Peter Moraw).

In the mid-1600s through the early 1700s there was a great growth in the number of colleges and universities throughout the western world – including in some colonies. This was the result of several religious revolutions, a starting industrial revolution, enhancement in world trade and the growth of a middle (entrepreneurial) class. The beginnings of a greater need to know the real physical world had been clearly enunciated (Francis Bacon, Novum Organum 1620, The Advancement of Learning, 1623). In the "New World" colony, Harvard College (1636) was founded and later became one of the great American universities. Since there was no official state religion in the colonies, all of the various sects could use their own college to proselytize their own particular religious beliefs but, of course, all were subject to "the crown". In particular, French intellectuals and writers were a profound influence at the end of the 17th and the beginning of the 18th century. There were also intimate interactions across borders and exchanges between the different combating states of Europe which somehow provoked intellectual exchange and technical change. Great musicians, composers, scholars, philosophers and scientists moved around and many of them emigrated to other countries (e.g., Handel and Herschel who went to England) mostly to look for good jobs. The creation of Cyclopedia and Encyclopedia [Chambers, Universal Dictionary of Arts and Sciences (1728) and Diderot's Encyclopedia (1755)] opened up a wide area of inquiry – Thomas Jefferson advised James Madison to buy these books.

There were major changes underway in England in 1760-1860, although "the universities" (Oxford and Cambridge) remained organs of the state and the state religion. Even in this period, individuals who were "dissenters" (i.e., not members of the proper church) were debarred from holding any public office and from taking degrees at the English Universities. This was a time of technical advances through the industrial revolution. A growing group of individuals in England and the dissenting Scottish Universities and the North English Academies developed innovative curricula and areas of instruction [see Figure 7]. The ideals of the French Enlightenment (brought forth under an emperor), sparked many of the ideals in the industrializing England. In particular, the closing decades of the 18th century brought a new interest in education among forward-looking industrialists and professional men in the manufacturing centers. They recognized the need for integrating science with production, and the revolutionary developments in industrial techniques. They saw that the rapid expansion of urban communities led to a variety of civic problems and responsibilities.

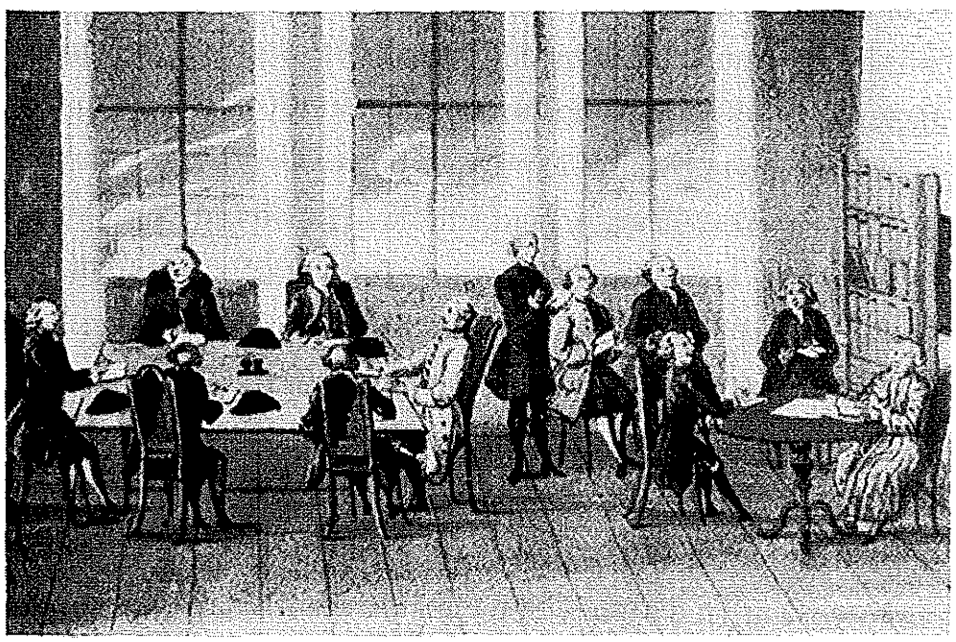


Figure 7. A college scene in the private residence of the Professor in Germany (1764). There are books, but no equipment to do experiments. The importance of discussion and intellectual interchange is evident. It is, of course, necessary to be able to discourse freely in a common language.

A group of these people founded "The Lunar Society" (1766). They met each month on the occasion of the full moon, holding informal meetings to conduct experiments and to discuss scientific topics. The meetings covered topics from a profound interest in the advancement of science and technology to a broader interest in social and political questions and, not least, the question of education. Among the members were James Watt (the inventor of the steam engine), John Dalton (the chemist), Joseph Priestly (the chemist who later emigrated to the American colony and became an early member of the American Philosophical Society, 1769), Erasmus Darwin (grandfather of Charles Darwin), and Josiah Wedgwood (the pottery maker). Darwin wrote a book entitled "Female Education" (1797) in which he advocated a broad curriculum for women including chemistry, mineralogy, astronomy, mechanics, optics, electricity and magnetism "for the more useful cultivation of modern science." Wedgwood was a great industrialist-inventor. He modernized ceramic manufacturing (1760) following the discovery in 1707 in Meissen, Germany that it was possible to produce porcelain of almost the same exquisite quality as was manufactured in Japan and China which, at that time, controlled the world's fine porcelain market. The production of fine ceramics had spread from China to Korea and on to Japan. There was a major flowering of the ceramics industry in Japan. The information transfer, from Japan to Meissen to Sevres to England, grew out of the desire for new trade and profits to be had from new or competing technologies. The French Emperor initiated a study of the results from Meissen, Germany. This new technology then flowed to Sevres and to Limoges in France and from there to England – all in a period of less than 50 years [see Figure 8]. The improvements in porcelain production

Figure 8. Report to the King of France on the development of manufacturing porcelain in Europe. The technology is illustrated with cherubs.

were an early part of the chemical "industrial revolution." Technology transfer, particularly with the stimulus of profit, always works in a short time.

The political and intellectual enlightenment in France was a great stimulus – both in England and in the American colonies, and greatly affected the American Revolution. The French Revolution had very diverse consequences. The empire of Napoleon I that grew out of the First Republic carried both wars and the liberal spirit of enlightenment to Central Europe. This led to the development of a new Germany unified under Prussia, with new growth and a popular attempt (unsuccessful) to move toward the liberal ideals of the enlightenment. 1848 was a time of more revolutionary movements (also unsuccessful) in both France and Germany, affecting both university life and economic circumstances throughout the western world.

The discovery and application of the role of chemistry in agriculture (J. von Liebig, 1843) shifted this fundamental human activity into a union of science-technology-industry and agriculture. This union is where we are today, forgetting folk myths about an earlier, simpler and happier life – the "good old days" – and the imagined virtues of low technology and poverty. The advent of science into everyday activities has generated food, enormous luxuries and conveniences available to large segments of society and has also led to the difficulties and problems of a highly complex society with its many demands on the individual and the environment of our planet.

By the middle 1800's, a tidal change in the English Universities began with the founding of new schools and universities and some moves toward "universal" education. However, the class structure long prevalent in English society continued to govern both educational and university structures. The function of the universities was to serve as seminaries of the ruling class. This situation greatly changed and improved in the latter part of the 19th century and broader and high quality education became a growth industry in the United Kingdom. Many of the changes were due to interactions between visionaries and intellectuals in varying circumstances in several countries. They read each others' works and, in some cases, had direct personal contact discussing ideas with each other, thus promoting the exchange of ideas and solutions to problems.

Now let us follow Joseph Priestly's odyssey to North America at a time when suppression was rising in England following the French Revolution (1789). He fled England after his house was burned, other members of the Lunar Society had been seriously attacked, and colleges were closed [see Figure 9]. The new world that beckoned and welcomed Priestly was rather wild, expanding and disorganized. Colleges were being founded across the new country – William and Mary (1693), Yale (1701), University of Pennsylvania (1740), Princeton (1746), Columbia (1754), Rutgers (1766), Dartmouth (1769) – all colleges which were founded by and supported by churches. The victory of the American Independence movement in 1778 and the formation of the United States (Ratification of the Constitution 1798) left strong but injured ties with England. It showed a will on the part of the people of the newly united states to move ahead, to develop and to grow in a democratic republic. The University of Virginia was founded by Thomas Jefferson in 1819 after his term as third President of the United States. In 1833 Oberlin College opened its first coeducational class.

In Germany, following the Napoleonic conquests, there had been a major growth of professional schools. In Prussia, the University of Berlin was founded in 1810 and there was a sharp increase in the quality of training and technical development in

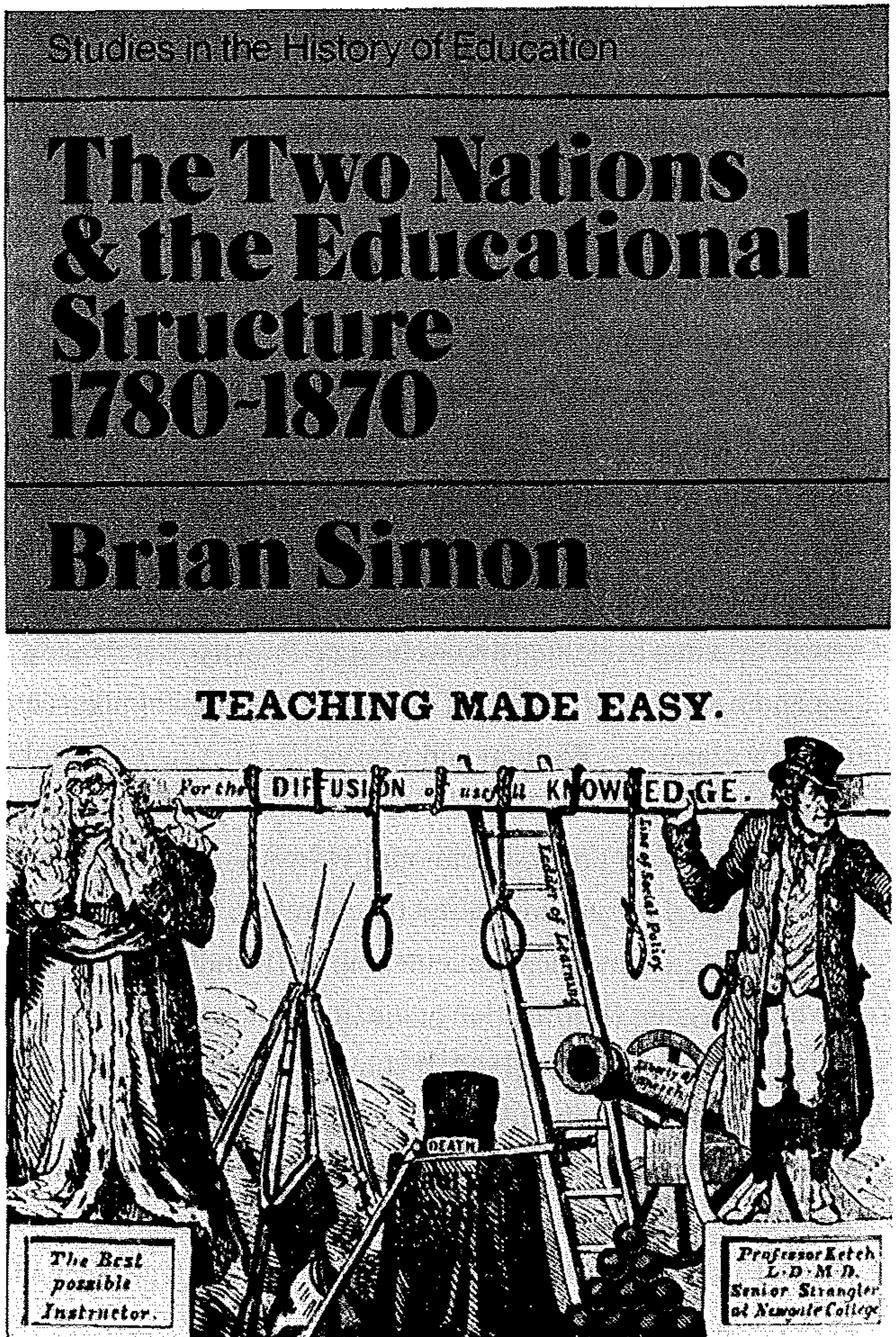


Figure 9. Cartoon showing the hazards of teaching from the trade union journal, Union Pilot, May 1832, used as cover for Brian Simon's book, published in 1960.

the German-speaking part of Europe, which moved instruction away from the line of encyclopedic scholarship toward an increase in specialized research work. Several U.S. universities then began to place professional schools and a research function inside of the academic structure in contrast to that typical of English colleges.

A major growth of American colleges and universities came from the practical need for trained people. The Morrill Acts, passed in 1862 under Abraham Lincoln (during the Civil War), was legislation that granted each state of the Union 30,000 acres of federal land for each member of Congress from that state. The lands could be sold to establish schools to teach "agriculture and the mechanical arts" (A & M schools). Some military training was required as part of the campus activity. After 1890 (2nd Morrill Act), Congress began to make regular (but small) appropriations to these land grant colleges. The Land Grant Colleges made research (agriculture and mechanics) a legitimate function of higher education and elevated the "useful arts, sciences and professions" to academic status. They also established a formal and direct connection between Federal and State governments and the universities for the first time in American history. The Land Grant Acts and colleges identified a research function as part of the college and also further emphasized the secular nature of higher education in the United States.

With the intrusion of Commodore Matthew Perry's squadron of the U.S. Navy into the port of Yokohama in 1853, there was the beginning of a real foreign trade by and with Japan. The Meiji Restoration in 1868 led to a revolution in the industrial economy of Japan and in its educational system. The recognized successes of Imperial Prussia and of Imperial Britain were studied and often followed. In particular, the Prussian model was closely emulated. The most important innovation was the founding of Tokyo University in 1877. In 1886 Tokyo University acquired the Imperial College of Engineering, and also inherited some aspects from the Tokugawa state. I note that the charge to the University under Article 1 of the Imperial University Order (1886) was: "The purpose of the Imperial University shall be to provide instruction in the arts and sciences and to inquire into the abstruse principles of learning in accordance with the needs of the state." The 1888 Imperial Rescript on Education by the Meiji Emperor provided the guidance on education and was stringently emphasized as one of Japanese history's most famous documents. (This order lasted until 1947 when Article 1 of the Fundamental Law of Education became "the goal of education is the full development of personality, the training of a mentally and physically sound people, and the creation of a love of truth and justice . . . and the independence of spirit to contribute to a peaceful nation and society.")

A case was made before the Japanese Diet that another institution was needed to eliminate the "academic evils that derive from the monopoly of a single institution." In 1897 the Imperial University of Kyoto was founded. Subsequently several other universities were formed although, as elsewhere in the world, there was never adequate financial support. Further, a host of private (i.e., non-governmental) colleges developed. In subsequent years the level of education grew in Japan so that national standards of literacy and training were as good as, or better than, in any other nation in the world. Japan now has over one thousand universities and four-year and two-year colleges (clustered around Todai). In Japan these are the arbiters of one's enduring contentment on earth.

In 1876, after the U.S. Civil War, the Johns Hopkins University was founded in Baltimore, Maryland. This was the first true University in the United States. It opened with separate graduate and undergraduate colleges – thus defining the difference between the education, training and research in professional schools as distinct from general education. Harvard and Yale soon followed suit. This approach emulated the structures developed in Germany. This was a period of intense, increasing development of the ongoing Industrial Revolution (chemistry, steel, transportation, agriculture, petroleum, information transfer and exchange). By this time, the dominance of the industrial, colonial and imperial powers of the world was in full evidence.

By the end of the 19th century and the beginning of the 20th century, remarkable changes occurred in the United States. Truly new universities – seats of advanced learning and of research institutes were funded and endowed by philanthropists. These individuals gave large to huge sums of their money to create exceptional, privately endowed schools and institutions which were open to the public. These included Vanderbilt University, endowed by Commodore Cornelius Vanderbilt (1873), the University of Chicago (1891) endowed by J. D. Rockefeller, Stanford University (1891) endowed by Leland Stanford, Carnegie Institute (1890) endowed by A. Carnegie and then merged in 1967 with Mellon University (1900), endowed by A. Mellon to become Carnegie-Mellon University, and the Rockefeller Institute (1901). These institutions opened up extraordinary opportunities, and were geographically spread across the nation. Their founding also set the stage for the role of private institutions and for competition among them.

For some time, two of the major competing financial benefactors were J. D. Rockefeller and A. Carnegie. As an example, I will cite Andrew Carnegie (1835-1919). Born in Scotland, the son of a hand-loom weaver, he fled to America and by the time of his retirement was a captain of industry. He was a rugged and ruthless individual but he was also fully aware of his debt to the "New World" and to society. He was antagonistic to the imperialism associated with finance capital. He established the Carnegie Foundation for International Peace, the Carnegie Institution of Washington (the first modern research institute) and public libraries throughout the nation. In one of Andrew Carnegie's essays he writes: "The best means of benefiting the community is to place within its reach the ladders upon which the aspiring can rise – free libraries, parks and means of recreation by which men are helped in body and mind; works of art certain to give pleasure and improve the public taste and public institutions of various kinds, which will improve the general condition of the people; in this manner returning their surplus wealth to the mass of their fellows in the forms best calculated to do them lasting good." "The man who dies leaving millions of available wealth that he was free to administer – The man who dies thus rich dies disgraced" (1900). Carnegie established a pension fund for U.S. college professors, was a benefactor of Tuskegee Institute (an institution for black students founded by Booker T. Washington), and established a trust to assist education in Scotland. His method was to build and equip schools and libraries on the condition that local authorities provide the site and maintenance. The Carnegie Foundation for the Advancement of Teaching (1905) made surveys of educational work carried out by Abraham Flexner which produced a revolution in education in the United States. The philanthropists and the competition among philanthropists to endow universities (some private and some state) has continued throughout this century to the present day in varying degrees (e.g. Arnold and Mabel Beckman, or more recently Bill Gates) – a very long list. It even got the little Keck (William Keck) telescope kickstarted. This competition persists at all levels within American Society today and involves the alumni of colleges and universities. All of these individuals of varying degrees of wealth (from extremely wealthy to just "well off") have the sense of repaying society in some small way for the benefits it had made available to them. The judicious act of giving away some of one's available wealth has become a means of achieving long-lasting fame and respect in order that one's name be remembered in a living monument as a true benefactor of society. Too often the money goes to buildings (e.g., monuments) and not to support the people who work in them. These monies are of great importance as a stimulus. They can not, however, provide the required, long-term, and growing support that is needed.

During this period of time (late 1800's – early 1900's) astronomy, astronomical observatories, experimental laboratories, and particularly instrumental developments, were in a state of vigorous growth in the U.S. Immigrants from many lands provided a continuing resource to the vitality of the United States. Albert A. Michelson's family left Poland in 1855 after the abortive liberal revolution of 1848 when purges became frequent. They arrived in the U.S. about 1856 to a mining camp near San Francisco. In 1887, the Michelson-Morely experiment had been done testing the ether drift theory using some of Rowlands gratings. Michelson had gone from the Navy to Case Institute of Technology (Cleveland) to Clark University in Massachusetts (endowed by philanthropist Clark, a furniture manufacturer) to the University of Chicago, with the enticement to move being, in every case, the promise of proper equipment, improved laboratory facilities and working conditions, and a college for graduate study free from the cramped and stultifying routine that typified most American education. American academic scientists in the late 19th century pressed for more support because they felt they were falling behind the major advances in German universities.

Great industrial research laboratories were founded in the United States in the early 20th century [General Electric (1900), Dupont (1902), AT&T (1912), Eastman Kodak (1912)]. The Mellon Institute for Industrial Research was set up and allowed smaller firms in less concentrated industries to drink from the fountain of scientific knowledge.

At this same time, a group of leaders of German science reported, "Today, at the beginning of the 20th century, German science, above all, the natural sciences, is in a position of urgent need . . . German science is already being overflown (namely by the Americans)" (1908). When Kaiser Wilhelm II opened the great hall of the University of Berlin (1910), he spoke of it as a "world university." This event was one of the forms of Imperial announcement of the state's existence as an advanced industrial society. From reports of visitors to the United States, the Kaiser had been impressed with the Carnegie Institution of Washington (1902) as an example of a true research organization, one that separated the direct connection between learning and research. The Kaiser Wilhelm Institute was then founded (1910) and partly underwritten by industrial financial sources, some from the chemical industry. This organization became the key research institute of Imperial Germany. These special institutes, often had university "connections" but were almost exclusively dedicated to scientific and technical research with major industrial relationships. The director of a research institute had greater prestige and power than a university professor. (After World War II, the successors to the Kaiser Wilhelm Institutes were the Max Planck Institutes (1949), now funded almost entirely by state money.) Indeed, one notes, as in many affairs that the appeal to national needs, the threat of being overridden by, or of being out-performed by, one's competitors, is an effective marketing scheme – even when it may not at all be honest or justified. It can have both positive and negative consequences.

In this epoch, experimental science was advancing quite rapidly in many countries. However, as regards theory, the main theoretical advances were being carried out in Europe and in the United Kingdom. The only truly outstanding theoretical work in the U.S. was done by the great J. Willard Gibbs (1839-1903) who studied three years in Europe, returned to write his magisterial, scientific contributions in a most isolated way at Yale. The most intense source of theoretical work had its location well outside of the U.S. where experimental and observational work were at the forefront.

In World War I, the U.S. was far less involved and far more fortunate than the European nations in terms of distance from the battlefronts with their enormous and tragic losses of human life. Leading up to 1914 there were significant changes in American colleges and universities. The Reserve Office Training Corps (1910) and the Students Army Training Corps became a part of campus life. The National Research Council (1916), was founded under George Ellery Hale's leadership as an offshoot of the National Academy of Science. Conflicts grew between the functions of the universities regarding teaching, research, research organizations, and the war involvement. After the war there were conflicting views on the roles of the government, the military and the universities. There were, of course, both positive and negative effects due to the war time experience. While acknowledging the positive results, President Lowell of Harvard drew the firm conclusion that military drill was absolutely incompatible with academic work and that "after a great war... it is wise to beware of a materialist reaction." An independent, private organization, the Academic Council on Education (1919) was founded to evaluate university education and contributed to assessing the state of universities. The entire post-World War I period was full of debate between those who thought the universities should place more emphasis on teaching and those scholars who demanded a greater accommodation to research. Certainly, it was found that research professors – with no teaching obligations – were not an acceptable part of the American University system. This gave way to the idea (but not the reality!) that "all university teachers were entitled to the chance to do research and they all had the responsibility to be productive scholars." At the "research" universities, the old distinction between "teaching staff" and "research staff" was becoming untenable. It took several decades to put in place a tenure ladder that forced junior faculty to climb up or to get out. Small revolving research funds and graduate research assistantships were increasingly adopted. However the state universities (not federal!) had their respective state governments as their sole patron. This required that they had to successfully make special appeals to the State legislature to accommodate faculty research. Some states, Michigan, Wisconsin, Minnesota, and California moved ahead to greatly strengthen their research and engineering capabilities.

The post World War I years saw important changes. The German ideal of a university dedicated to pure learning began to be discredited and American educators often looked to Oxford and Cambridge for inspiration. The "undergraduate experience" with fraternities, athletics and campus social activities began to take center state. "Going to college" began to be evaluated in terms of what one did, and with whom one was associated, rather than with what one learned and by whom one was taught. The extracurricular pursuits, the interaction with classmates and the overall socialization process became of main importance – "in earnest cultivation of those traits of personality most useful on the road to success." The "collegiate trend" ran counter to the ideas of higher education and research. The battle was on to establish admissions on the basis of intellectual merit and to establish traditions of academic performance with the prevalence of a serious and professional minded faculty. This was often in opposition to the idea that college life was for individuals from a special, more privileged class of "gentlemen" and not strictly for those judged for merit and performance.

By 1931 the U.S. was working at the frontiers of science with exceptional experimental work. However, the leading centers of theoretical studies in physics were in Europe – in Berlin, Munich, Leipzig, Göttingen, Copenhagen, Leyden, Zürich, and Cambridge, England. The newly founded Institute for Advanced Study (1932) attracted Einstein, Wigner and von Neumann, all of whom emigrated to the United States. By 1933 the great economic depression was in full swing and American institutes were in a poor position to expand. That same year, during the first wave of Nazi purges, 196 German academics (mostly Jews) were dismissed from their universities. Within a few years, this number became 1,000. In spite of the many difficulties, through the intervention of Niels Bohr and others, some 650 could obtain some academic affiliation in the United States. These included Debye, Fermi, Franck, Bethe, Courant, Szillard, Teller, etc., etc. This great intellectual migration to the U.S. was one of the key components in establishing the golden age of research in American universities and the forthcoming scientific and technical advances in the U.S. This intellectual migration did not cause the ascendancy of science in America but confirmed it and expanded it. These immigrants were, to some extent, the seed bed for new ideas and a means of training the next generation of exceptional individuals. Both the existing research universities and the developing universities were thus able to move ahead into the forefront of research by the time that World War II began.

Then the horrors and tragedies of the Second World War were unleashed. The economic problems and serious unemployment of the Great Depression disappeared into the sea of deficit spending toward armaments. The effects on the U.S. University and research establishments were drastic. Military uniforms became commonly visible on campuses, the officers training corps suddenly became a part of university instruction and activity. This involved a change in university function, and provided a new federal financial resource in place of the usual tuition and limited endowment sources. The professors of science and engineering became intimately involved with problems of the war effort. Major research enterprises were rapidly developed which deeply involved the university communities and war-related institutions began to be founded and operated with the participation of, or under the guidance of, both state and private universities. Great industrial-scale, applied research laboratories were developed, most of them secret. The research universities of that time became involved in enterprises in which the federal government and in particular, the armed forces played a managerial and financially supporting role. Industrial needs and demands were generated that also involved the universities. The results were highly effective in enhancing a wide variety of technologies useful to the nation in support of the war effort. New technologies and new approaches were developed within this complex, vigorous framework with its pressing deadlines. Whole new modern industries such as the design, fabrication, testing and manufacturing of aircraft blossomed with mutual efforts on the part of both industry and academia (for example, Caltech and MIT). The final end of the war with the joint assault by the western allies and the Soviet Union on the European continent and the dropping of nuclear bombs on Hiroshima and Nagasaki terminated with horror, the horrors of the war.

The U.S., which had been shielded from battles on the American continent, promptly began to disband its large military force and released most of its soldiers and sailors into civilian life. With concern over employment and the obligation to train-the returned service men (almost all of whom had been conscripted for military service), the government inaugurated the "GI Bill" which provided support (including books, tuition and minimum living expenses) to the returned service men to use while studying in the colleges, universities, or trade schools of their choice. The GI Bill provided enormous financial incentive to the universities and an incredible opportunity to millions of young men who would otherwise never have had the opportunity of higher education. It also brought in students who were mature, eager to learn, dedicated, and hard-working. They recognized this was a special opportunity.

I was most fortunate to be one of these individuals. I returned from service to graduate from high school. My father hired a tutor to teach me simple basic mathematics, then I attended night school where Rutgers College (then in the process of becoming a State University) gave classes for advancement. Then I was admitted to study in the regular "daytime" university.

The GI Bill opened up the structure of American Universities to the broad public, not just the prepared elite. It enhanced university income and opened up a new vista of education in the U.S. It also directly connected federal and state governments in the functions, goals and finances of the universities and enhanced the involvement of these governmental offices with the university functions and goals.

At the end of W.W.II, the professors who had been intimately involved in the war effort and who had become used to large-scale, high quality, technical support in their work – these individuals almost all returned to their universities. The government now had large, complex, military-industrial research centers dispersed across the nation. The government had also come to recognize that science and technology were an integral part of the whole society. The military now recognized that they required the guaranteed participation of people with very high levels of technical and professional expertise.

Various offices, such as the Office of Naval Research (ONR), applied federal funds to support unclassified, i.e., not secret, research at universities. The Atomic Energy Commission (AEC) initiated pre-doctoral fellowships, post-doctoral fellowships and research programs at universities, jointly with AEC laboratories. These fellowships and research ties established close connections between the returned university community, the new university community and the federal laboratories and centers. Prior to the end of W.W.II, President Roosevelt directed Vannever Bush (from MIT) to advise him how to apply the war time government experience in sponsoring scientific research after the cessation of hostilities. The report *Science – The Endless Frontier* was the charter for post-war federal science policy.

The National Science Foundation was then founded (1950) with the charter of supporting basic research – unrelated to military or "national" needs – in universities, not in federal centers. Subsequent growth of the research enterprise in the U.S. was related to matters involving the Cold War with a highly insular Soviet Union and with its great military forces. The civilian space program was enormously advanced with the launching of Sputnik by the USSR. The interplay of real external threats, perceived needs, and real needs, was, as before, a complex melange. Great advances took place, frequently governed by a desire to announce a national presence or eminence. This often had very positive effects. However, the competition in the military area directed industry in both the U.S. (by cost plus profit incentives that are more typical of war time) and the USSR (by edicts of the Central Committee) to produce advanced, complex systems which no one wanted to use and for which there was no direct commercial market. It enhanced the political power of federal (or national) agencies by defining job and financial "markets" that were not productive in the economies and were governed by deficit spending. The U. S. has fortunately recovered from this pattern of spending, due I suppose, to a "free market" and entrepreneurial economy. Termination of this competition and threat was, most fortunately for humanity, without the outbreak of a nuclear war. The USSR is now disbanded and the individual states which comprised it are unfortunately left with great internal problems that will affect the future of the community of nations and which must be addressed.

My home institution is Caltech where I have been since 1955. It was founded by the visionary leadership of George Ellery Hale who had been at the University of Chicago and who persuaded the streetcar millionaire C. T. Yerkes to provide the University with the world's largest refractor telescope. Hale went to the Carnegie Institution of Washington and persuaded them (in 1904) to build the Mt. Wilson Observatory (after he staked $30,000 of his own money to get it started). He was a seer and a believer in "Big Science" and stressed the importance of organization and cooperation in scientific research. Moving to Pasadena, California as the new director, Hale began to take an interest in "Throop University", which was a local trade school – not a college or a university. He recruited the distinguished chemist, Arthur Noyes, from MIT (1913) and then the famous physicist, Robert A. Millikan (1919) from the University of Chicago. In 1920, the school became the California Institute of Technology. The trio of Millikan, Hale and Noyes recruited individuals from all over the world, individuals highly talented in both teaching and research, and sought and got financial support. The Institute began to attract (and often keep) outstanding students – Linus Pauling came as a graduate student in 1922, became a faculty member in 1927, and was named Chairman of the Chemistry Division in 1937. By 1930, Caltech ranked as one of the leading producers of important papers in physics in the country. Caltech was often referred to as Millikan's school. When Millikan retired, Lee A. DuBridge, who had been director of the Radiation Lab at MIT, became president of Caltech (1946) immediately after World War II. DuBridge sought to continue the excellence in teaching and research, and to enhance his staff of exceptional faculty. Hale had sought resources from the private sector and feared and avoided support from the government. Millikan had generally been of this viewpoint. There had naturally been the deep involvement with federal support as a result of the W.W.II. Now the fundamental problem DuBridge had to face was how to obtain adequate financial support and not compromise the full independence and traditional character of academic institutions. This balance has consistently changed, with an increase in funding from the federal sector, not only at Caltech but in all research universities. Even the Carnegie Institution of Washington, which eschewed government support, changed its policy during the 1970s to permit funds from government grants.

My personal experience has been devoted to research, developing instruments and teaching. The funding sources that aided me were originally some important start-up funds from Caltech, small grants from the NSF, a Sloan Foundation fellowship that provided key money for new research endeavors and substantial longer term grants from the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) that provided the basic support for my laboratory (The Lunatic Asylum). The laboratory's name reflects that fact that the "inmates" have all been seriously affected by the moon! I have had the privilege of being deeply involved with the Apollo missions and have served as an advisor to NASA for a twenty-year period and have chaired the Committee on Planetary and Lunar Exploration of the National Research Council. I have spent a good deal of effort seeking funds each year to obtain adequate support to operate the laboratory and to develop new techniques and approaches. My views reflect the above experience.

In considering the role of research, we see from the history outlined above that research is needed by society, by government and by industry. The mechanisms for carrying out research are in industrial, governmental, public [i.e., state = prefectural] and private universities and institutions.

Industrial research institutes employ professional people who have been trained in universities, supplemented by industrial experience. The research work carried out in these institutes seeks to address the short and long term needs of that industry or corporation. In general, this work is not in the public domain – it is usually "industry confidential." The personnel turnover is relatively slow and by retirement except when there is a major turnover due to restructuring of the laboratory and redirection of laboratory goals.

Government research institutes are in the direct service of the federal government and may often provide some national facilities. They may be operated by the government directly or for the government by contract with an industry or a university. These institutes are not on University campuses, but at distinct and usually distant locations. They hire professional people trained in universities and from industry. Those who conduct research in the public domain (e.g. National Institute of Health (NIH), NASA, some DOE, the Department of Agriculture, etc.) do so under the acts of Congress that founded them (*cf* the Space Act which put the civil space program squarely in the public domain with free flow of information). The NIH is a key player in biological-medical areas. It functions under the "Health" umbrella. It is not a university nor should it be turned into a Federal university or graduate school. That would be a grave danger in my view. Those research centers carrying out work in the defense domain are dominated by classified research but often also carry out outstanding fundamental research. Almost all of these centers are committed to applied science and engineering. There is and will be an ongoing need for very high quality research, usually applied, directly related to national security issues. The personnel turnover in all government laboratories is usually slow and is governed by retirement.

There are exceptional private research institutions such as the Carnegie Institution of Washington that do pure fundamental research. Except for research fellows that may bring some renewal, the personnel turnover is slow and governed by retirement.

The universities dominantly do fundamental research, usually not directed by national needs (in peace time) but often reflecting national commitments and sometimes national need. They train students in experiment and theory, in recognition and selection of problems and the means of attacking them, and in finding new problems and techniques. All of this is in the public domain. While faculty turnover is not rapid, there is annual rejuvenation by the fresh rain of new students and research fellows. This is the seed bed for new approaches, new inventions and discoveries in both pure and applied science. These individuals are not simply trained professionals. They are the intellectual capital of the nation and will be the prime movers of the future.

Many nations with National universities use funding systems for universities, both in terms of their teaching function and of their research function, through a Ministry of Education [see Figure 10]. In contrast, the U.S. does not have any "National" universities and the funding for research from the now dominant

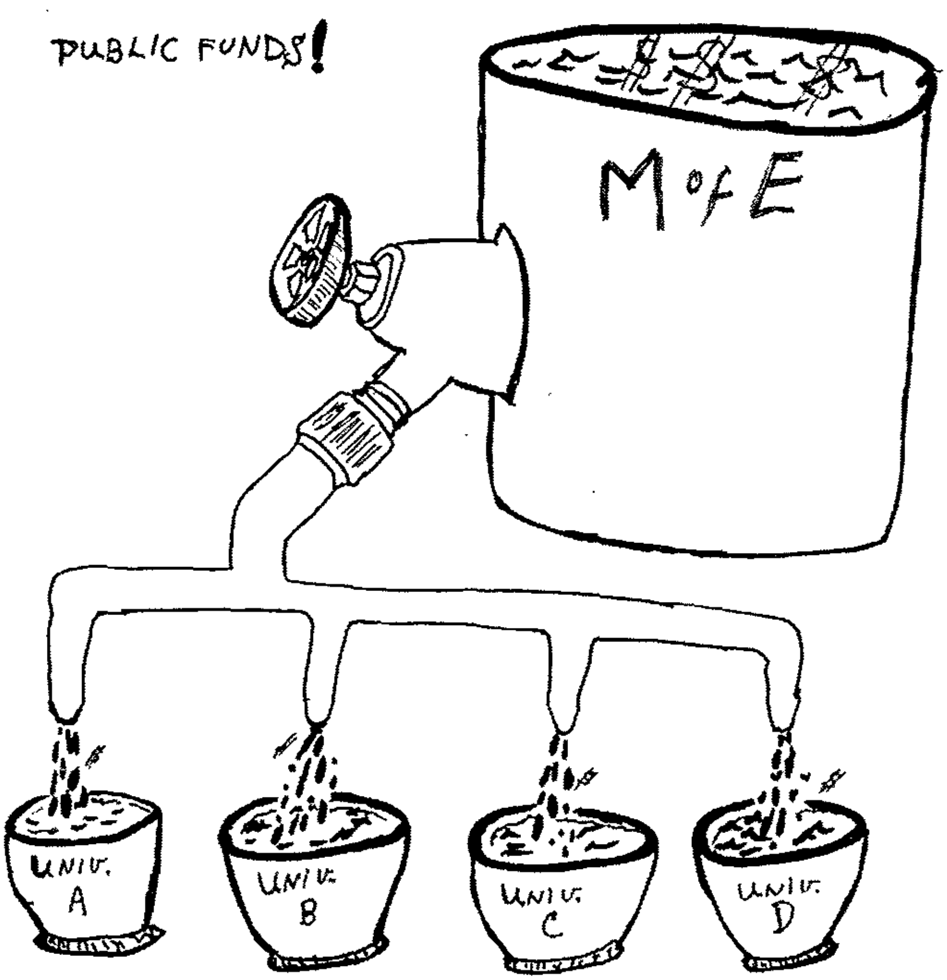


Figure 10

federal sources is governed by the method sketched in Figure 11. An individual scientist in a university (state or private) may (with the approval of the University administration) apply to any number of different programs carried out in various agencies. These programs have as their goal the support of the agency program. The agency seeks scientific research in support of this goal. Insofar as this does not involve any classified (i.e., secret) work and is fundamental research in science or engineering, the university usually approves the submission. The federal agency, both by reviews (external peer review and internal review) and in consider-

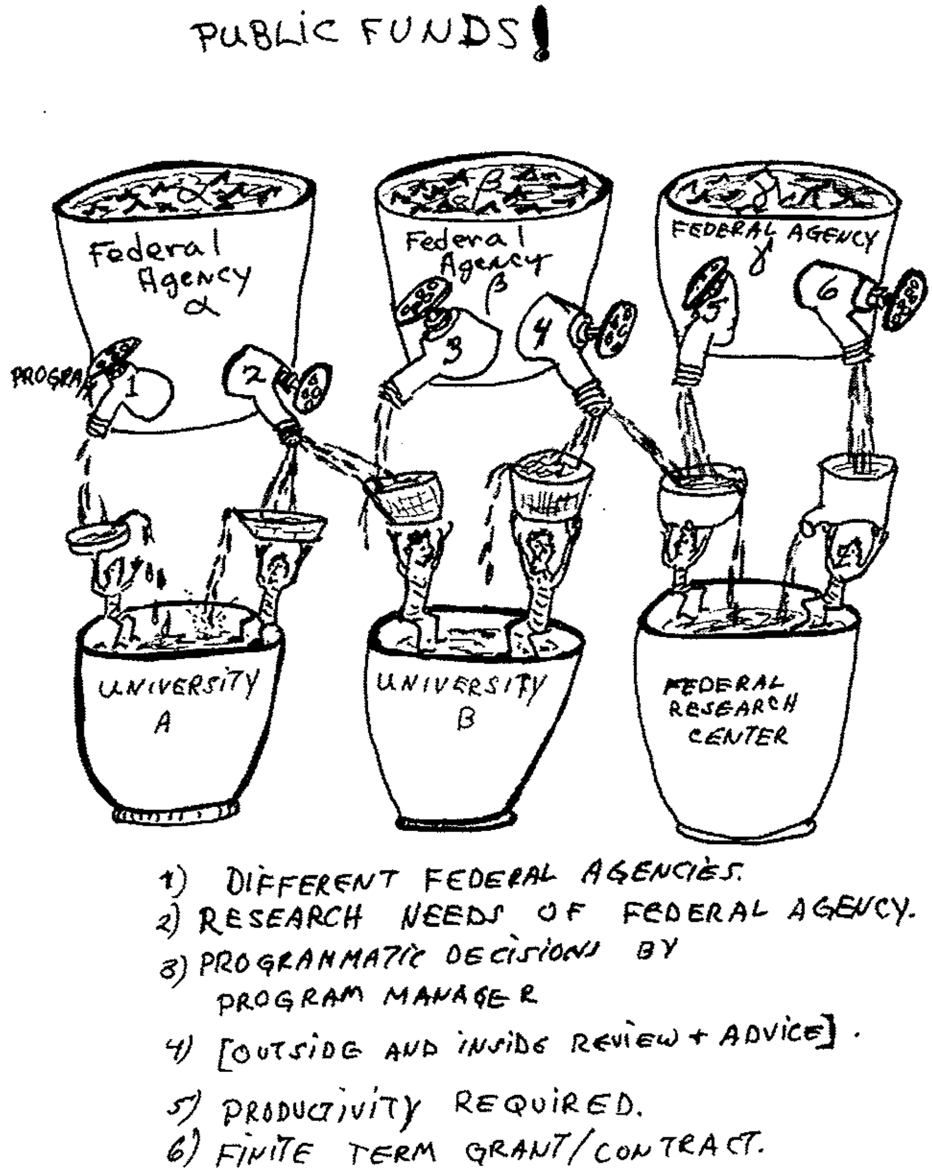


Figure 11

ation of the agency objectives and the applicant's qualifications, may choose to make a grant or a contract to the university with the applying scientist as Principal Investigator (PI).

With regard to "peer review", that is so critical to the funding agencies in identifying high quality research programs, there are no magical or satisfactory approaches. Obtaining honest, competent and critical reviews of proposals, particularly reviews that are constructive, is exceedingly difficult. One can often get blanket endorsements with little guidance, micro-criticisms, or hypercriticisms that often reflect protection of the reviewer's "turf." Good, objective, critical evaluation that reflects program goals and scientific or technical objectives are not easy to obtain. Innovation is not readily accepted even within the scientific community – it is emulated when it is successful. Innovation is also not usually supported by peer review. The Program Manager must have excellent judgement in coming to decisions and will often depend on an outside advisory panel. However, this panel should only be advisory and not in control of the final decisions. The agency must choose technically competent and broadly knowledgeable program managers who have a sense of science and the scientific community as well as of the agency. There is always a danger that the program manager either becomes just an agent of the agency or a captive of the scientific community associated with the program that he/she manages. As always, insight, wisdom and courage are needed.

University acceptance of a proposal submitted by a professor then becomes a commitment of space and resources on the part of the university and a commitment on the part of the professor or Principle Investigator (PI) to carry forward the research. Output is almost always papers published in the open literature in scholarly journals and the impact of these works. The monies that come in, go in part to the university (overhead and staff benefits ~50%). The remainder is at the disposition of the PI for equipment, supplies and salary support for students, research fellows and technicians. The grant usually must cover laboratory operation, and refurbishment. The advantage of this approach is that it enhances the opportunity to move ahead in different research endeavors, attracts students, and greatly supplements the equipment and staff within the university. The "property" bought with the grant usually then belongs to the university. This has been the fundamental building block of the US university research program and has been remarkably successful. The role of tuition in research universities continues to be significant but is no longer the dominant source of income in private research universities.

The dangers associated with this means of funding are: 1) The professor becomes an entrepreneur; 2) A large effort is expended by many faculty in the effort to come up with a good and marketable proposal; 3) The university becomes a contractor with the funding agency and hence with ties to the federal government; 4) The university profits (i.e., gains income) from these contracts but growth is not controlled. Growth and activity become confused with the university function; 5) The university as such, no longer provides infrastructure for research but depends on the PI's; thereby diminishing a real university capacity; 6) The fight over money is, of course, ongoing and as the number of scientists in a field increases or as the dollar support decreases, the "fight per buck" gets very intense; 7) The allegiance of the professor to the university and the university community is substantially diminished [see Figure12].

With regard to the competitive nature of this system, there is always an intense level of competition per dollar and some of the participants barely hang on [Figure 13]. When the budget level decreases, the fight per dollar intensifies and many individuals fall out of the field [Figure 14]. In most cases, the budget is cut proportionately by management and leaves a full community of weakened or incapacitated participants, i.e., it is as if all the scientists have the tips of the fingers cut off, yet everyone

+ POSITIVE

1) Diverse sources
2) Healthy competition
3) Student support
4) Staff support
5) Entrepreneurial professors
6) Good equipment
7) University increases income
8) Vital research efforts

– NEGATIVE

1) Large fund raising effort
2) Focus away from the University and teaching
3) May reflect agency needs excessively
4) No long term support
5) Unhealthy competition
6) May overextend the University

Figure 12

remains in the program. In my view some of these financial difficulties are the result of excessive proliferation of some research enterprises. It is possible that this could be, in part, corrected by limiting the number of groups in a field where substantial or major instrumental and laboratory needs are required. It is neither nec-

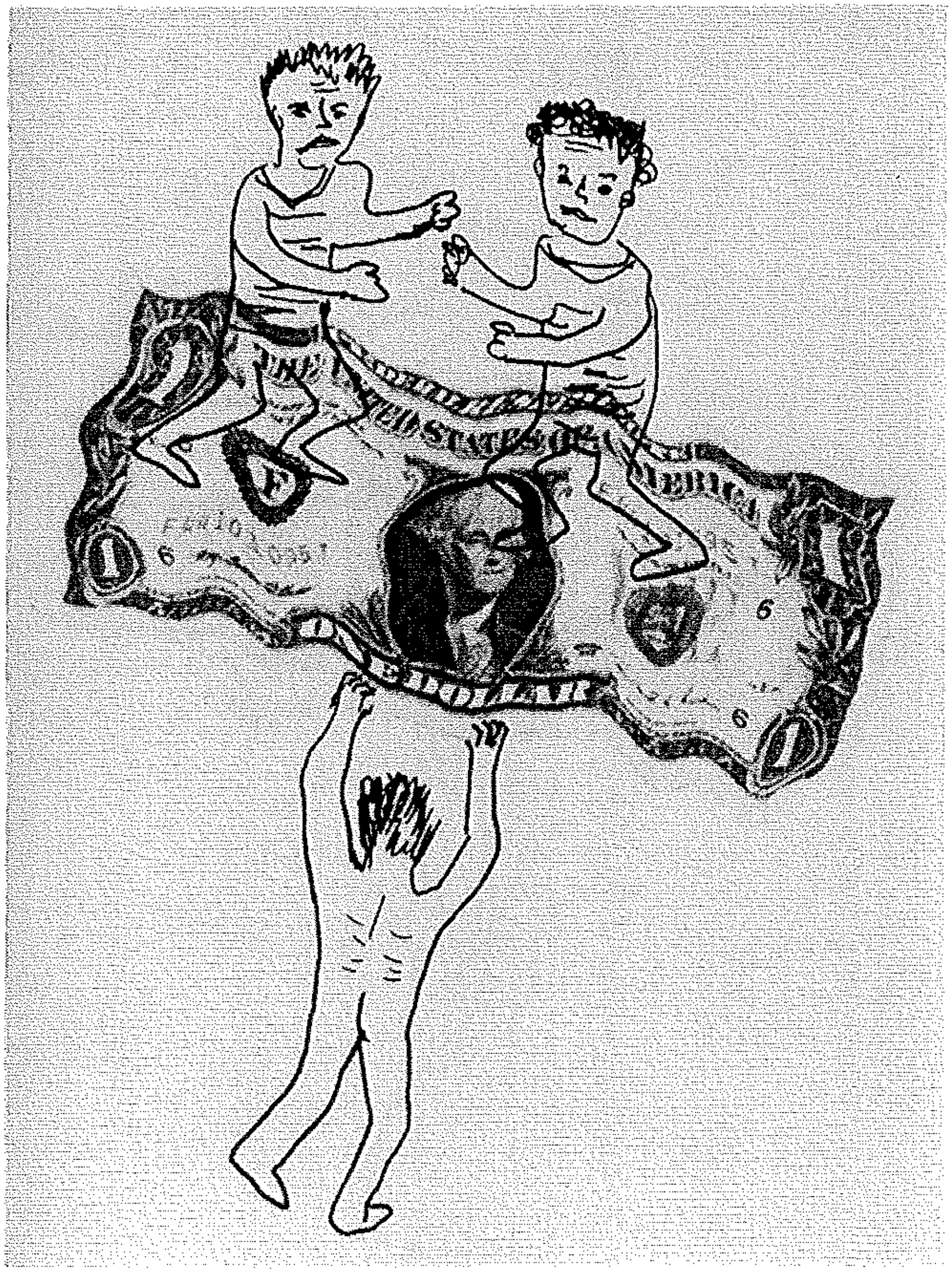


Figure 13

essary, nor desirable, for all research universities to be active and great in all fields. The universities, when considered as a total assembly, should cover the important areas of science. In many cases, the infrastructure to support some laboratories is grossly inadequate, particularly with regard to support staff and maintenance of complex systems. It would be better if laboratories with

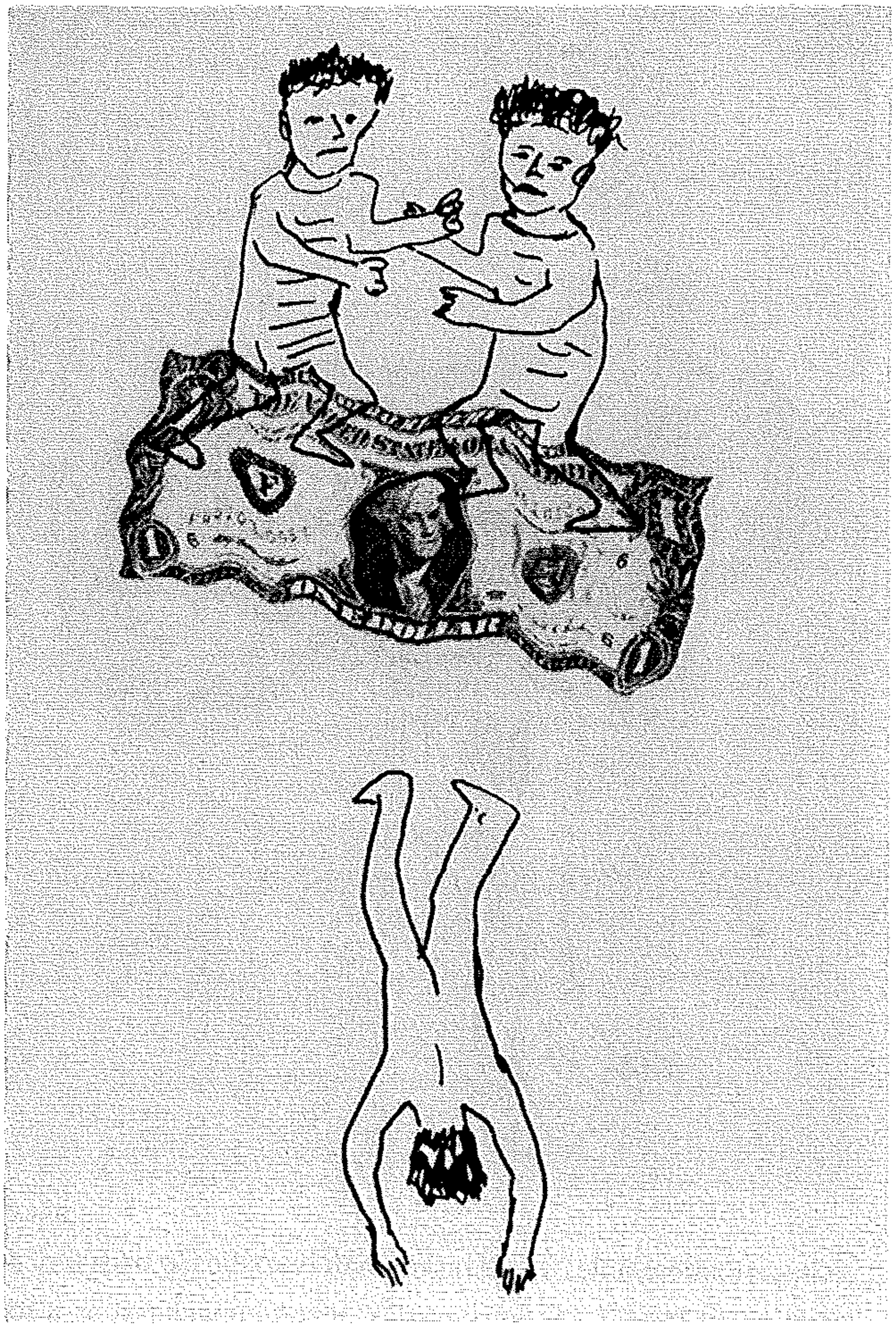
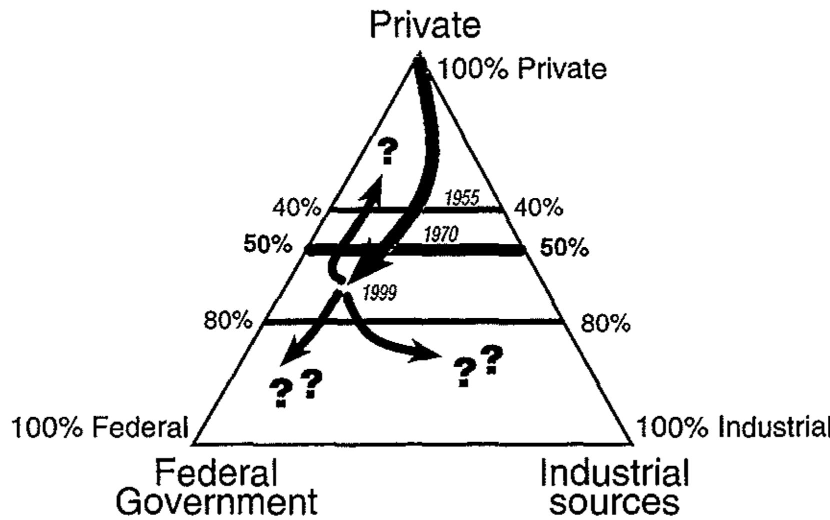


Figure 14

high technical competence were provided with the support staff necessary both to carry out their own research and to maintain the sophisticated instruments. They could then provide both ac-

The "Private" Research University (U.S.A.)



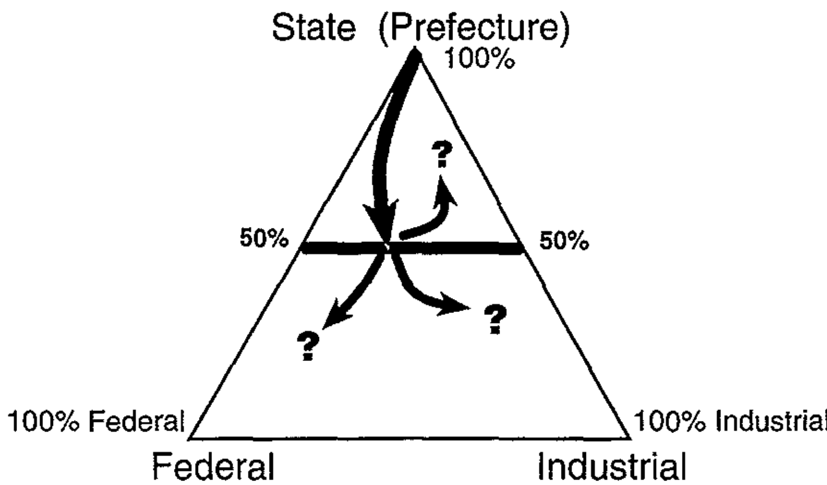


Figure 15

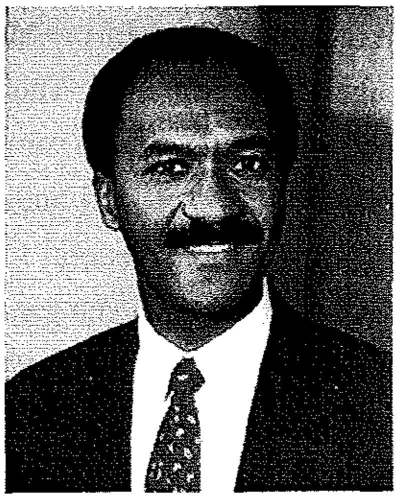
cess and training to "Users" from other groups. This would free resources so that user groups could develop those important ancillary research skills to optimize use of the instruments. At the present time, a large number of research teams are understaffed and underperforming, unable to maintain technical operations that are outside of their expertise and resources. Some of the political problems can be assuaged by having a broad geographical distribution of each scientific area, but every school cannot be outstanding in everything. In any case, as Hale stated: "The best science" approach should govern the allocation of scientific resources.

I have represented the fiscal evolution of private research universities in a triangular diagram [Figure 15]. This diagram shows the percentage of total annual university financial expenditures for research and education from private sources, (that is, university endowment, philanthropic gifts and tuition) from industrial contracts and grants, and from Federal contracts and grants. The top of the triangle with 100% private resources is the end member. (For example, the line marked 50% corresponds to one half of the income being from private sources. The amount received from Federal sources could range along the line from the remaining 50% being completely federal funds to all 50% being from industrial sources.) In considering the extent to which private universities are independent of the government, I have sketched my guesstimate of the trajectory of a typical "private" university with time. It can be seen that at present, well over one-half of the annual income is from Federal sources. If we look at state universities in the same representation, there are major quantitative differences, but the trends are similar. In the U.S. we appear to be at the juncture when the private resources give some independence, but are not the dominant force in determining the functional capability of the university. Instead, these resources are more like an ancillary support unit.

This leaves us with three questions: 1) Should the private universities continue along this trajectory?; 2) Can they continue along this trajectory?; 3) What other paths are open? With regard to the first question, my opinion is NO! The integrity of private universities is a direct reflection of their independence. Their positive value and contributions to society are founded on some sort of financial independence. With regard to the second question they can only continue along this path if more Federal resources become available. I do not think that is likely. The great increase in the number of research universities in the U.S. over the past 50 years has automatically provided a great increase in competition for Federal resources that will limit further evolution along the current trajectory. The support of the U.S. Congress is considerable, but the point has been raised that growth itself is not the answer [Figure 16].

If we cannot continue along the path shown (that is, increasing Federal support) what paths are open to us that we should follow? One clear route is to substantially increase the proportion of private endowments. This private endowment should be used in support of ongoing university activities, for rebuilding the infrastructure of the research university, and to start in new directions while eliminating some old obligations and obsolete directions. A second pathway obviously lies in involvement with industry. This involvement provides both great opportunity and great problems. As indicated in the cartoon-graphs [Figure 17], an intrinsic conflict lies between the openness of universities and the secretiveness of industry and of government defense agencies.

Arrangements with the government in non-defense areas are open, so conflicts regarding free inquiry are much diminished. In defense and national security areas, there have been some mechanisms established that place subjects in a sort of neutral area which permits free inquiry and still makes critical ideas and



Franklin D. Raines
Director, Office of Management and Budget

Questions from July 1998
Franklin D. Raines, Director
Office of Management and Budget

1) **How large a scientific enterprise does this nation need? More is not an adequate answer!**

2) **How do we set our priorities in the nation's Research and Development enterprise?**

3) **How should the success of Federal programs be measured?**

4) **How can government-university partnership be evaluated?**

5) **How can the American people be engaged in the excitement and wonder of science?**

Figure 16

information available to the defense establishment. The latter arrangements must, of course, be subject to very critical review with an automatic sunset clause (a pre-set time when the joint agreement between university and the government are to be terminated). This is not always done.

If we focus on industrial sources, it is necessary to identify mechanisms that truly permit free inquiry, are within the framework of universities (which are tax exempt!), and that must serve the public good. It is now necessary to begin some discourse with leaders of industry to try to identify possible programs. Some great philanthropists from industry have already shown major ways to support universities. However, the more

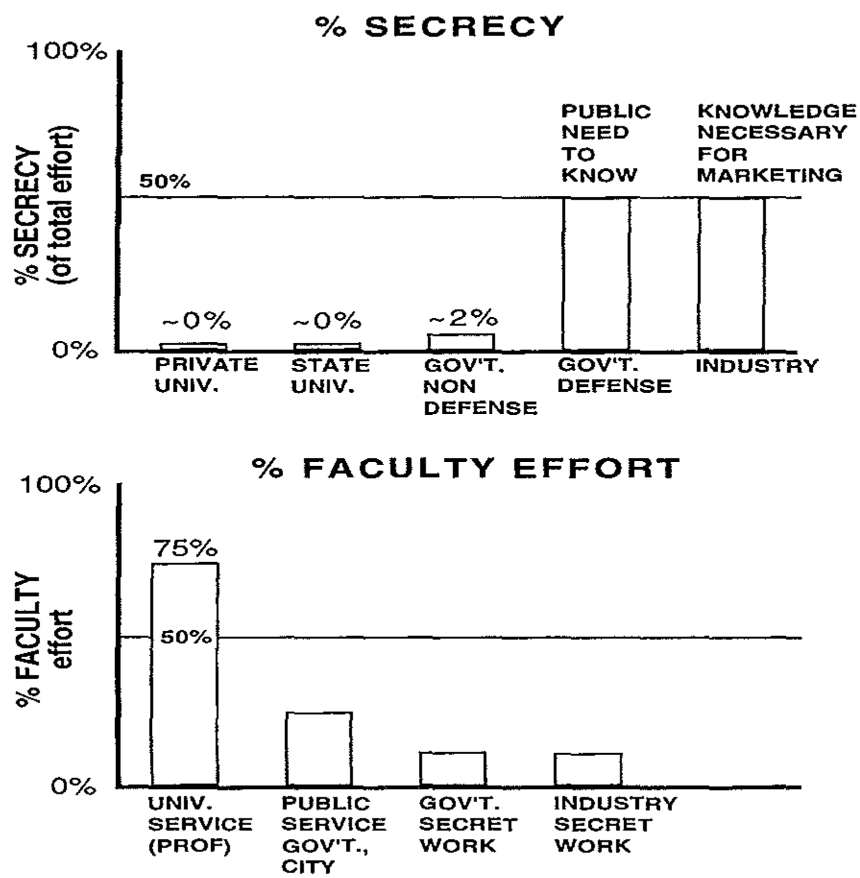


Figure 17

direct interactive relationships between industry and the university have not been resolved due to the wall of secrecy. The matter of severe industrial competition (short- and long-term) and the inability to define "neutral areas" where free investigation and exchange of information may take place – these matters are completely unresolved. They must be resolved to the benefit of both industry and of the public "common good".

The other possible mechanism to turn the trend toward the private end member is to have the research universities become profitable. This effectively means that the University becomes a kind of industry and is directly involved in making money. This is anathema to the goals of a university and should not be done. A mechanism that might permit the "reverse movement" is that of licensing agreements that allow the use of innovations developed in the research university to be used by industry. These agreements would permit the marketing of inventions and patents held by the university (and the government!). There are great benefits and great dangers involved. There is the enormous risk that the professors become industrial entrepreneurs and only use their university position as a base for making money as members of industry. This is becoming a real threat in the United States. A more reasonable approach is to encourage innovation and invention within the university research program by patent agreements. The relationship with outside companies and the transfer of technologies and techniques should be through students who have graduated. These students can either set up new companies or go to work for existing ones. The new start-up companies are by far the most important as they truly provide new opportunity, new jobs, and innovation to the society at large. They must be encouraged and nurtured by venture capital and shielded in their early years from predatory monopolistic practices. As far as "the professors" are concerned, they should not be corporate officers or agents of any companies. The problem of how to solve secrecy issues between professors, students and research groups and the withholding of information because of the intrusion of direct financial profit motives into the university research, has not been well addressed anywhere. At present the major activity in these areas is in biotechnology – who owns which gene sequence and how to share samples and information. All of this conflict comes from the hope of high potential profits – this has become a major activity and a major fear in several research universities in the United States.

In general, the trajectories of individual scholars in U.S. universities is not governed by the first or second school they attended. It is quite possible to move up to higher performing institutions based on an individual's promise, potential or performance. This permits a great deal of openness and exchange within a university and the broader society of universities. The faculty at most great universities in the U.S. come from a wide selection of schools, not just one or two. At Caltech, the faculty come from over one dozen universities, some of them not well known except for the exceptional scientist that they produced and we hired. They may come from many countries. We do not use a "sole source" system at Caltech or in the U.S. in general. We also have lots of immigrants in the U.S. Some arrive with incredible skills and many others have no training but are highly motivated to succeed, trying to improve their circumstances and they or their children often respond very well to the opportunities offered. While there is always lots of friction between the groups, the general movement has always been toward acceptance, assimilation and integration into the society, both academic and social.

The vitality and health of research universities in the U.S. is directly related to the existence of both private and state schools. The private schools have had sufficient independence that they can choose various approaches without either scrutiny or control by the government. This enhances innovation and experiments in approaches. State schools have larger resources from the tax-based support. But they are more restricted by the requirements of state legislatures. They have major requirements in re-teaching as well as in teaching. The class loads and requirements often reflect the state's requirements. However, state universities work with many very good people, both professors and students. When the state universities concentrate their resources for research, they have become major and leading research universities. However, they also have obligations that private institutions do not have. The competition between the state and private universities is an important basis for the vitality of both institutions. Scientists can be and are lured from one place to another based on better working circumstances, better students, better equipment and better support. This works both ways between the best schools and is dependent on the vision of the academic leadership. When there is no benefit in "moving", there is no encouragement to either the professor or the university to improve. This positive competitive enhancement (with benefits) for professorial positions in research universities is usually missing in many countries.

The problem with research universities in the U.S. is, in part, the result of their success and the enormous growth in their number over the past four decades. Given the limit of fiscal and intellectual resources, this growth has produced and will produce problems which often are the result of extensive overlap and competition within the same research area by many universities. It may also reflect the political pressures to "distribute the wealth". The universities in all countries are all subject to great stresses and great futures [see Figure 18a,b]. We can learn much from someone else's "system" but cloning is not a solution [Figure 19]. Most importantly, the universities have been tardy in independently assessing and re-evaluating their goals and restructuring themselves in order to achieve their desired objectives.

As I indicated in my introduction, universities are social institutions. They are subject to many of the same rules and problems as cities – there are many analogies. Analyses of the vitality,

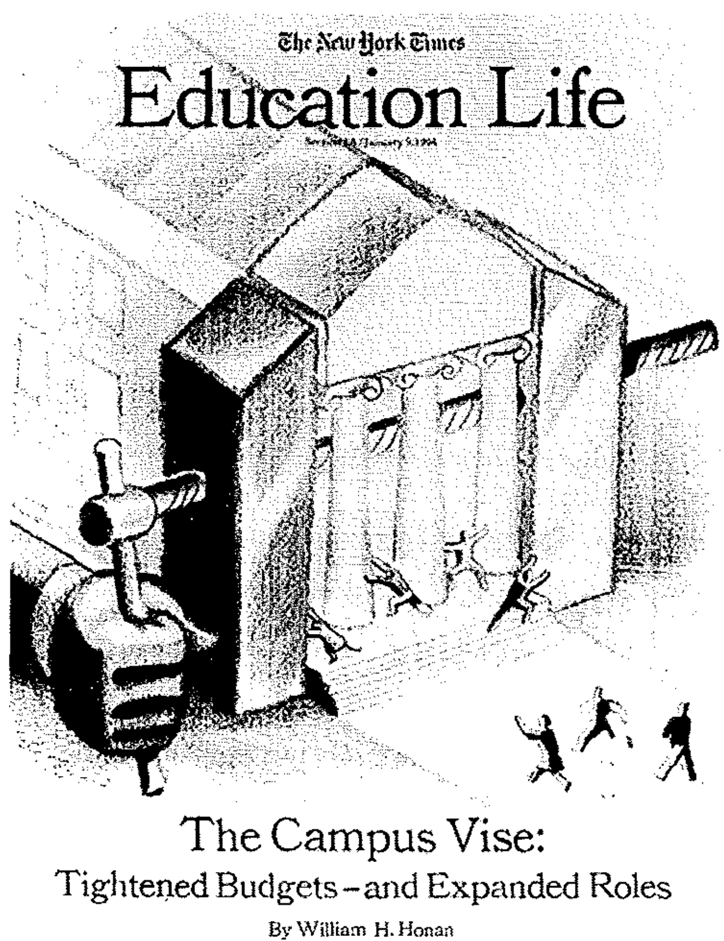


Figure 18a. Reproduced by permission of the New York Times.

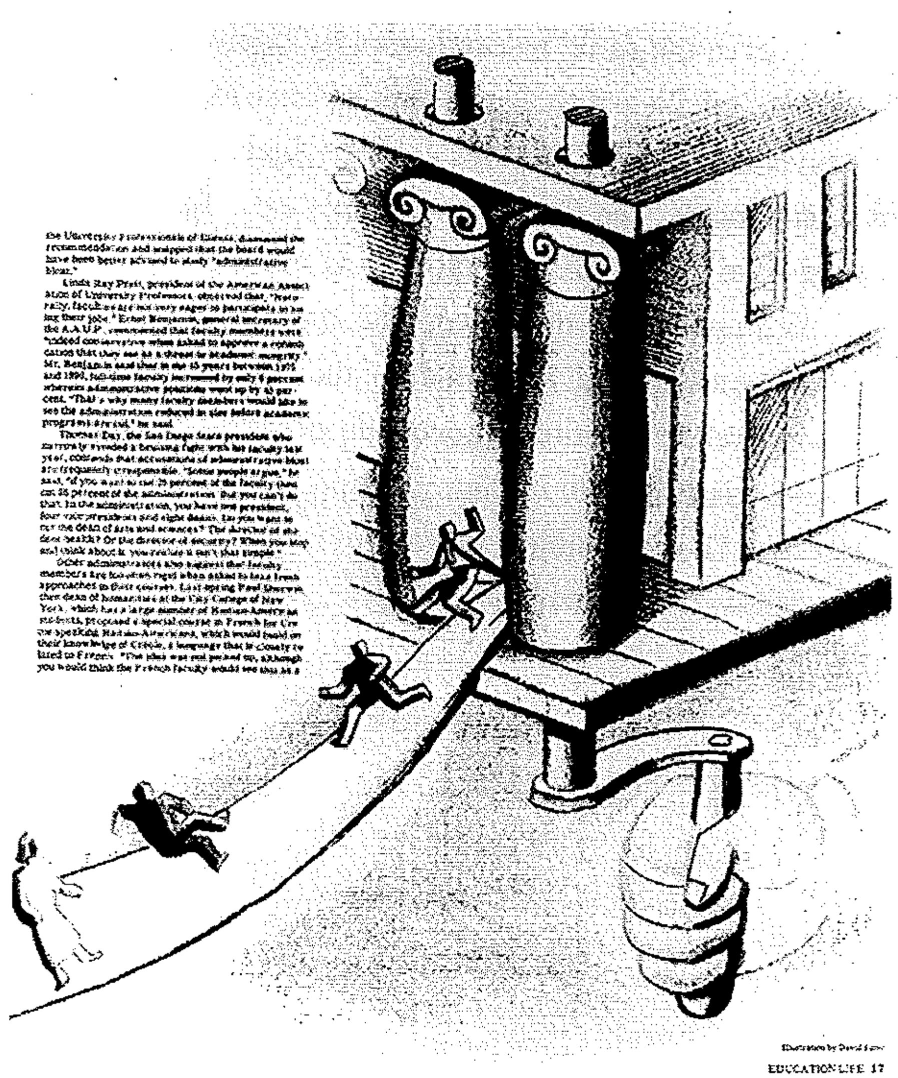


Figure 18b. Reproduced by permission of the New York Times.

virtues and vices of great cities has been lucidly describe by Jane Jacobs (Cities and the Wealth of Nations, The Economy of Cities, and The Death and Life of Great American Cities, Random House, New York). One may write an analysis of universities using her study simply by changing examples and the names of functions. In the United States, there have been a series of problems concerning universities. This is, in part, due to the excessive replication of some functions (i.e., too many universities with the same agenda is similar to having too many coffee houses or

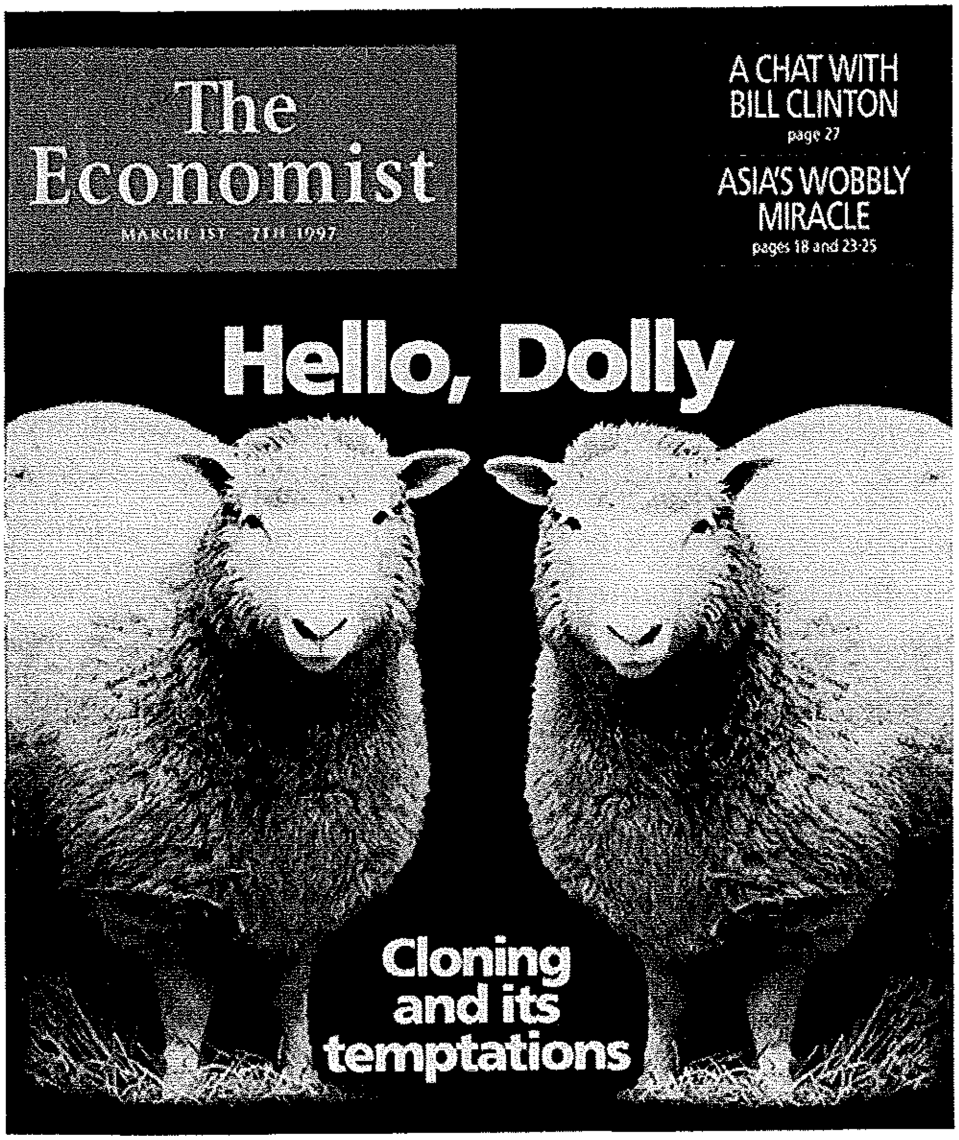


Figure 19

too many shoe stores in the same city). The great expansion of the number and activities in universities cannot continue to exponentiate. We must carefully guide and train our students to recognize that there are worlds of opportunities and that there are many ways to make significant and beautiful contributions to society.

The students must be trained for greatness and diversity both at the undergraduate and graduate level. However, the ability of the students to envision a variety of career opportunities must be aided and encouraged. Certainly, the current procedure of extending post doctoral fellowship positions to long time periods is an unhealthy scheme. Only a few students are cut out for, or destined to be, a "University Professor".

The key issue is what the university gives to society. It has always been the education and training of bright young people who come to the research universities to learn how to learn. People who invent and create new ideas and things that did not exist before create whole new fields of endeavor. The real jobs that will exist in the future are not the ones that exist today. We cannot train for jobs that are – they will not exist for long. We can educate and train for the new jobs which the next generation of brilliant and creative young people will bring into existence. It is the responsibility of a great university to bring bright young people into our laboratories and to let them loose on their own problems with the guidance and mentoring of a few faculty members.

This approach was emphasized by Edwin H. Land, the inventor and founder of the Polaroid Corporation and a college drop-out. In a speech at MIT in 1959 he pointed out that simply giving tests and examinations is not an adequate preparation for life [see Figure 20]. The bright young student requires an usher, someone who guides them into a personal research project and who also aides and guides the student in meeting other scientists. The purpose of a great university is to encourage independent, creative thought and independent choices of problems to be attacked, to try to understand some aspect of the universe.

In thinking about universities, I believe that we should consider universities as a means of creating new understanding, new possibilities, new problems and some new solutions. There

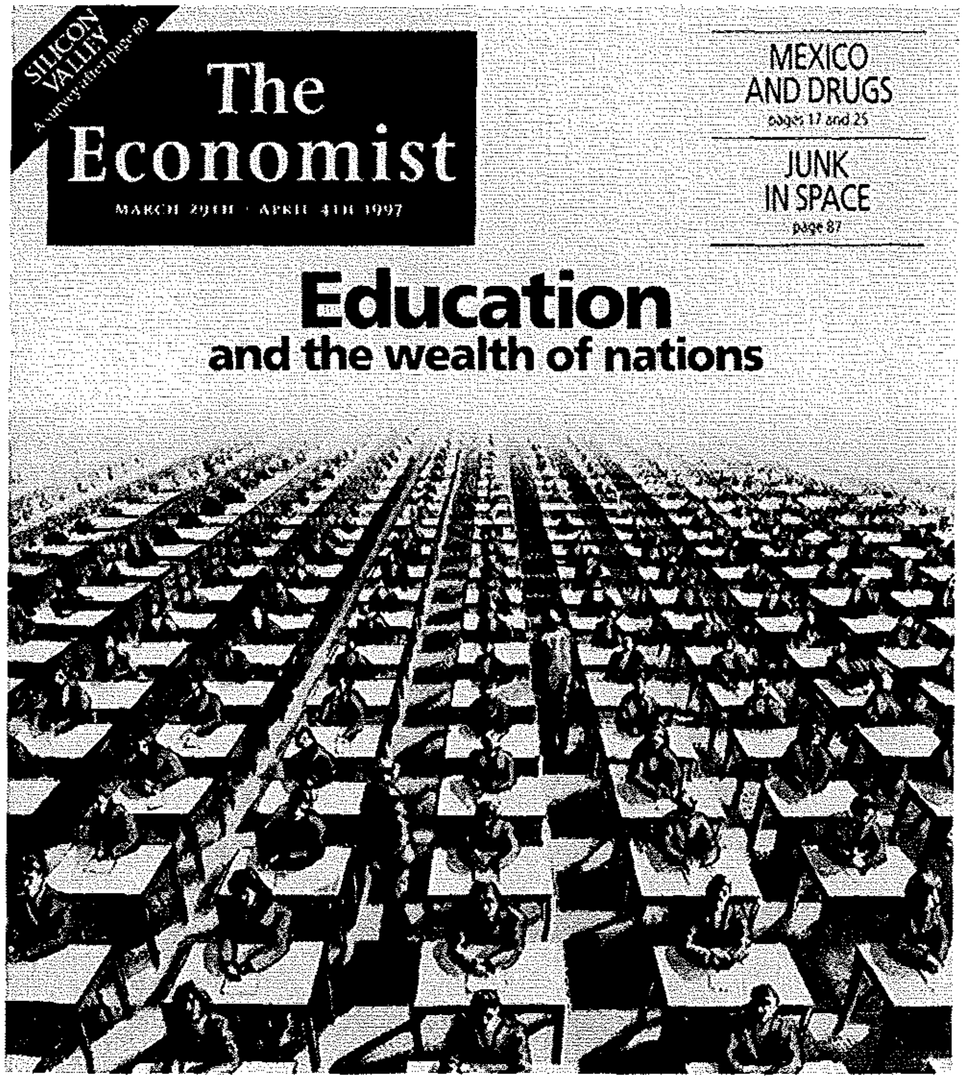


Figure 20. Is this a classroom?

is not a unique "streamline" of learning.

The different rivers of learning flow into the sea of knowledge. Each river has its own character and is made up of a myriad of small brooks and streams, each with its own chemistry and each flowing over variegated terranes. They are all refreshed with new rain and melted snow that comes from the sea to cut channels in new ground. The new rains are the students.

Thank you for your attention and your patience.