Chapter 5

Education and Human Resources for Research and Development

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Findings

OTA found that major Federal actions designed to affect the supply of manpower to perform research and development (R&D) in the area of information technology would appear to be unwarranted at this time. Forecasts of future manpower needs in this area are replete with uncertainty. Moreover, developing manpower for the specific areas where potential shortages might tentatively be predicted would be particularly hard to accomplish through broad Federal actions. The educational backgrounds and skills required to meet these potential shortages are at once both too broad and too narrow to be developed at the Federal level. In addition, given the length of time required to develop skills and the rapid changes taking place in the area of information technology, Federal action, taken now, might prove to be inappropriate in the future.

A number of legislative proposals have been made that are designed to increase the future supply of highly qualified scientific and technical manpower. These proposals differ considerably in terms of their goals, their targets, their costs, and their scopes. Given the high levels of uncertainty that surround the present manpower debate and the number of competing uses to which the Nation's limited educational resources might be profitably put, the most prudent course might be to adopt those policies that would provide for the greatest amount of flexibility and the broadest range of skills.

The Concern About Manpower

In the United States today, there is a growing and widespread belief that the Nation's poor economic performance is inextricably linked to the relative decline in the size and the quality of its technical work force. Noting that Japan and West Germany, our major international competitors, have four times as many electrical engineers and computer scientists, per capita, as the United States, many of the people who hold this view fear that, as the economies of the developed world become more technologically intensive, and thus as R&D becomes more critical to their success, the United States will increasingly lose its ability to compete. Typical of this perspective is the statement made by Representative Margaret Heckler during hearings on Engineering Manpower Concerns, when she said:[1]

> To maintain its technological edge in world markets the United States must reemphasize science and engineering on our agenda of national priorities. When the Soviets launched Sputnik I, a remarkable engineering accomplishment, the United States rose to the challenge with new dedication to science and technology. Today, our technology lead is again being challenged, not just by the Soviet Union, but by Japan, West Germany, and others.

The negative consequences of having a shortage of manpower in information technology R&D, it is argued, may be particularly severe. Given the speed with which the field is changing, even a temporary shortage might impair the ability of information technology industries to remain at the frontiers of re-

[1]Representative Margaret Heckler, Opening Statement, *Hearings On Manpower Concerns,* before the Committee on Science and Technology, House of Representatives, 97th Cong., 1st sess., Oct. 6-7, 1981, p. 4. For a more recent statement of this perspective, see also, *Hearings on Mathematics and Science Education,* before the Committee on Education and Labor, House of Representatives, 98th Cong., 1st sess., Jan. 26-28, 31, 1983; see also, *America's Competitive Challenge,* Report of Business-Higher Education Forum, 1983.

search. And, because the information technology industry represents the fastest growth sector of the economy, failure to keep pace in this industry may have serious consequences for the Nation's economy as a whole.

Concerned about the state of available human resources for high-technology jobs, spokesmen from business, government, and education have called on the Federal Government to undertake a number of significant educational measures and reforms. These measures range widely in terms of goals, targets, costs, and scope. Some of them, for instance, focus on a specific curriculum area, such as math and science; others emphasize educational infrastructure—the training of teachers and the need for equipment; while still others seek to foster new modes of cooperation between business, government, and educational institutions. Given our Nation's limited resources and the growing number of demands and stresses that are being placed on our educational system at all levels, choices and decisions will have to be made about which goals to pursue and about which measures to adopt.

Notwithstanding the widespread discussion and concern about the poor state of the Nation's manpower resources, there has been very little systematic effort to clearly identify and characterize the nature and the extent of the problems. Before making any major policy decisions designed to affect the supply of manpower, therefore, it will be necessary to have a greater understanding of: 1) what we know and don't know about the relationship between manpower development and economic growth; 2) what we know and don't know about this relationship as it relates in particular to R&Din information technologies; 3) the range of projections about the future supply of and demand for manpower in this field; 4) the ability of the present institutional structure to accommodate these manpower needs; 5) the role of the Federal Government in the development of manpower; 6) the societal context in which, today, decisions about education will be made; and 7) the range of Federal alternative strategies and options for meeting future manpower needs in the area of information technology R&D. The following discussion provides a preliminary basis for such an understanding.

The Relationship Between Manpower Development and Economic Growth

The assumption of a positive relationship between the size and quality of a nation's work force and its economic wealth is not a new one. Over 100 years ago, for example, the British Government sponsored a parliamentary committee to investigate the causes of rapid industrial growth in the United States. Like many of our recent studies of economic growth in Japan, the British parliamentary committee attributed much of America's industrial success to the superior education of the American worker.[2]

Indeed, ever since the beginning of the industrial revolution, economists and other social observers have argued that a skilled and educated work force is the most productive. Writing as early as 1776, Adam Smith, for example, pointed out that "the skill, dexterity, and judgment with which it's [the nation's] labor is generally applied," is the primary factor determining the size of "the fund which originally supplies it with all the necessities of life. "[3]

'Report *From* the *Select* Committee on *Scientific* Instruction, Parliamentary Papers, 15, (1867-1868) Q 6722, as cited in William Abernathy, Kim B. Clark, and Alan Kantrow, *Industrial Renaissance: Producing a Competitive Future for America* (New York: Basic Books, 1983).

³Adam Smith, *The Wealth of Nations* (New York: The Modem Library, 1937), p. lviv.

As modem societies became more technologically advanced, an increasing amount of attention was paid to the development of the labor force. Anticipating the effect that technology would have on society, the German sociologist, Max Weber, pointed out for example, that, in an advanced industrial society, the organization of human relations could no longer be left to chance. Instead, human beings become factors of production-their

Present government policies designed to affect the supply of manpower are also based on this assumption. However, as the following discussion illustrates, while we can identify some general linkages between education, manpower, and economic development, our understanding of causal relationships, or of relationships in specific situations, is extremely limited.

While acknowledging that having qualified manpower is critical to the success of a nation's economy, social and economic analysts are still unable to fully account for, or to completely explain, the nature of the relationship between the size and the skill level of the labor force and economic growth and development. As the economist, Nathan Rosenberg, has noted:[4]

> One of the central historical questions concerning technical progress is its extreme variability over time and place. . . . Clearly the reasons for these differences, which are not yet well understood, are tied in numerous complex and subtle ways to the functioning of the larger social systems, their institutions, values, and incentive structures. The explanation of these differences is intimately tied to such even larger questions as why social change occurs and why economic growth proceeds over time and place.

Not only is each piece of the puzzle difficult to solve; the whole problem is subject to the vagaries of external events, well beyond our anticipation and calculation. Nor are the tools of analysis particularly refined. For—although demographers may tell us something about population trends; sociologists something about the institutions and processes in which individuals are recruited, educated, and trained for work; economists something about the point at which, and the rate of exchange by which, the supply and the demand for labor are brought into a state of equilibrium-historians are sure to remind us that it is, more often than not, a unique set of circumstances that has had the most significant effect on a particular outcome.

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relationships to be structured in accordance with there quirements of industrial progress. And the American economist, **Thorsten Veblen**, writing in the 1930s, went so far in his discussions of technology and society as to suggest that, for technology to develop to its full potential, the technical expert-the **engineer—would** have to play a key role in society's decisionmaking process. Jay Weinstein, ***Sociology/Technology:*** *Foundations of Post* ***Academic Science,*** **Transaction Books, 1982, p. 32; Thorsten Veblen,** *The* ***Theory*** *of the Leisure* ***Class*** *(New* **York: The Modem Library, 1934).**

[4]**Nathan Rosenberg,** ***Inside*** *the* ***Black*** *Box–Technology* ***and Economics*** **(Cambridge, MA: Cambridge University Press, 1982), p. 8.**

Identifying Particular Manpower Problems and Solutions

Our limited knowledge of the role of human resources in economic growth and technological change is clearly evident in our efforts to identify and analyze specific manpower problems and solutions. For although manpower specialists might agree that having sufficient qualified manpower is critical to a nation's economy, they do not necessarily agree about the number of people who are required to meet the employment needs of a particular sector; about the kinds of skills and experience that might be required to perform particular kinds of jobs; or about the way in which these skills might best be obtained or developed.[5]

To identify future manpower needs in a particular area, policymakers have traditionally relied on economic and other forecasting methodologies. While useful as policymaking tools, these methodologies are subject to a number of problems and weaknesses which stem, among other things, from imperfect data, weak forecasting models, and ill-founded assumptions.[6] To be most useful, forecasting methods need to be flexible and responsive. Acknowledgment should be made of the limitations of these methodologies, and efforts should be undertaken to verify their results by conducting frequent surveys and by performing case studies designed to determine

[5]**National Institute of Education,** *Education, Productivity,* ***and*** *the National Economy, A Research* ***Initiative,*** **December 1981; see also Edwin Mansfield,** *Education,* ***R&D, and Productivity*** *Growth,* **revised, University of Pennsylvania, Jan. 31, 1982.**

[6]**R. H. Bezdek,** *Long-Range Forecasting of Manpower* ***Requirements*** *(New* **York: Institute of Electrical and Electronics Engineers, 1974).**

the changing skill requirements that are linked to the emergence of new technologies.

It should be noted, moreover, that manpower forecasts can themselves produce a pendulum effect, underminingg the validity of the projections. This effect results from both the long period of time that it takes for people to prepare for afield of work, and from the fact that, once committed to a career path, people rarely change their plans in midstream to adapt to new circumstances. Upon hearing predictions of an impending manpower shortage in a particular field, for example, an inordinate number of students may seek to pursue such a career, hoping that when they have finished their educations, jobs will be plentiful and competition will be in short supply. The resulting manpower glut will appear only later; but predictions of it may induce a number of students to avoid the field, leading to another shortage in the future.

It should also be remembered that manpower predictions can be interpreted differently by different kinds of people. Economists might describe a shortage, for example, when they see a rapid increase in wages due to a gap between the supply and demand for labor. Businessmen might consider that there is a shortage of manpower when they are dissatisfied with the quality of preparedness of the pool of people from whom they have to select employees. New graduates may interpret a manpower shortage to mean that they face little competition in seeking employment.

The problem of predicting manpower needs in the area of information technology R&D is even more complicated, because the field is new and in a rapid state of flux. There is, for example, very little historical basis for identifying who the people are who might typically perform R&D tasks in the area of information technology; what skills they should possess in order to perform these tasks most effectively; or what their optimum career patterns might be.

It is only very recently that either the National Science Foundation (NSF), the key agency mandated to monitor the supply and demand of engineers and scientists in the United States, or the Bureau of Labor Statistics, have begun to treat computer scientists as a distinct group. NSF, for example, has only recently stopped labeling everyone who works in a computer-related field as working in the area of computer theory, a heading that was itself a subcategory of mathematics. And, even today, NSF does not list a department of computer science under that heading if the department's name appears in a combined form and if the words "computer science" appear second in that combination.[7] Even when the appropriate statistics have been collected, moreover, they have often been subject to a variety of interpretations.[8]

It is also difficult to determine not only who or how many people are working on or with these technologies but also who or how many people are performing specific R&D tasks in this area. NSF estimates that in 1981,3.1 million scientists and engineers were employed in the United States. Of these, 47 percent were employed as engineers (including engineers do ing management jobs), and 13 percent were working as computer specialists (see fig. 20).[9] NSF reports, moreover, that 34 percent of all scientists and engineers are involved in R&D activities"[10] (see fig. 21). As table 24 illustrates, compared to other countries, this is a high proportion of R&D scientists and engineers relative to the total labor force. Figures are not available, however, for the percentage of scientists and engineers who specifically perform R&D tasks in the area of information technology.

Use of aggregated data based on broad skill categories or outmoded technologies reduces the value of manpower demand forecasts. A category such as computer programmer, for example, is much too broad to use for forecasting manpower demand in R&D. Further sub-

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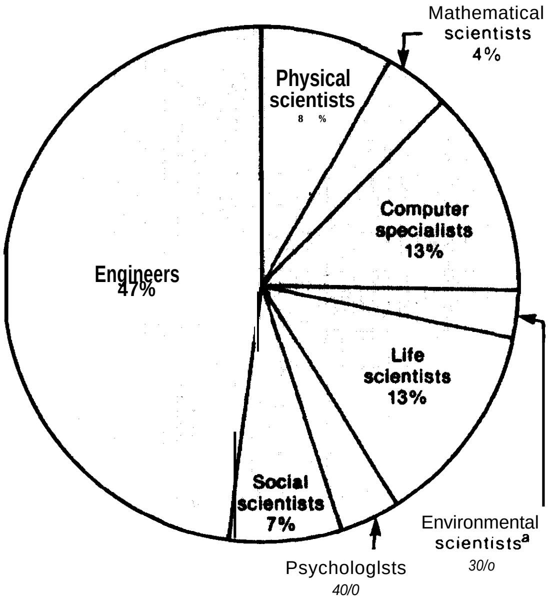
[7]Kent K. Curtis, "Computer Manpower-Is There a Crisis?" (Washington, DC: National Science Foundation, January 1983).

[8]Ibid.

[9]*Science Indicators 1982: An Analysis of the State of U.S. Science, Engineering, and Technology*, National Science Board, 1983, p. 63.

[10]Ibid., p. 66.

Figure 20.-Employed Scientists and Engineers by Field, 1981



[a]Includes earth scientists, oceanographers, and atmospheric scientists.
NOTE: The total number of scientists and engineers m 1981 was 3.1 million.
SOURCE: *Science Indicators,* 1982.

division into types such as entry level, applications, and systems programmers based on existing job specifications, while useful, will probably not suffice for long, since the mix of computer-related skills required for R&D is especially sensitive to technological innovation.[11] Some of the most important skill categories, for example, lie at the frontiers of information technology, and these do not show up in the broad categories based on aggregated data. The problem of identifying these skills, therefore, is not just one of substituting one set of static descriptors for another; it is a problem of gathering information about new skills over time and in response to changing conditions.

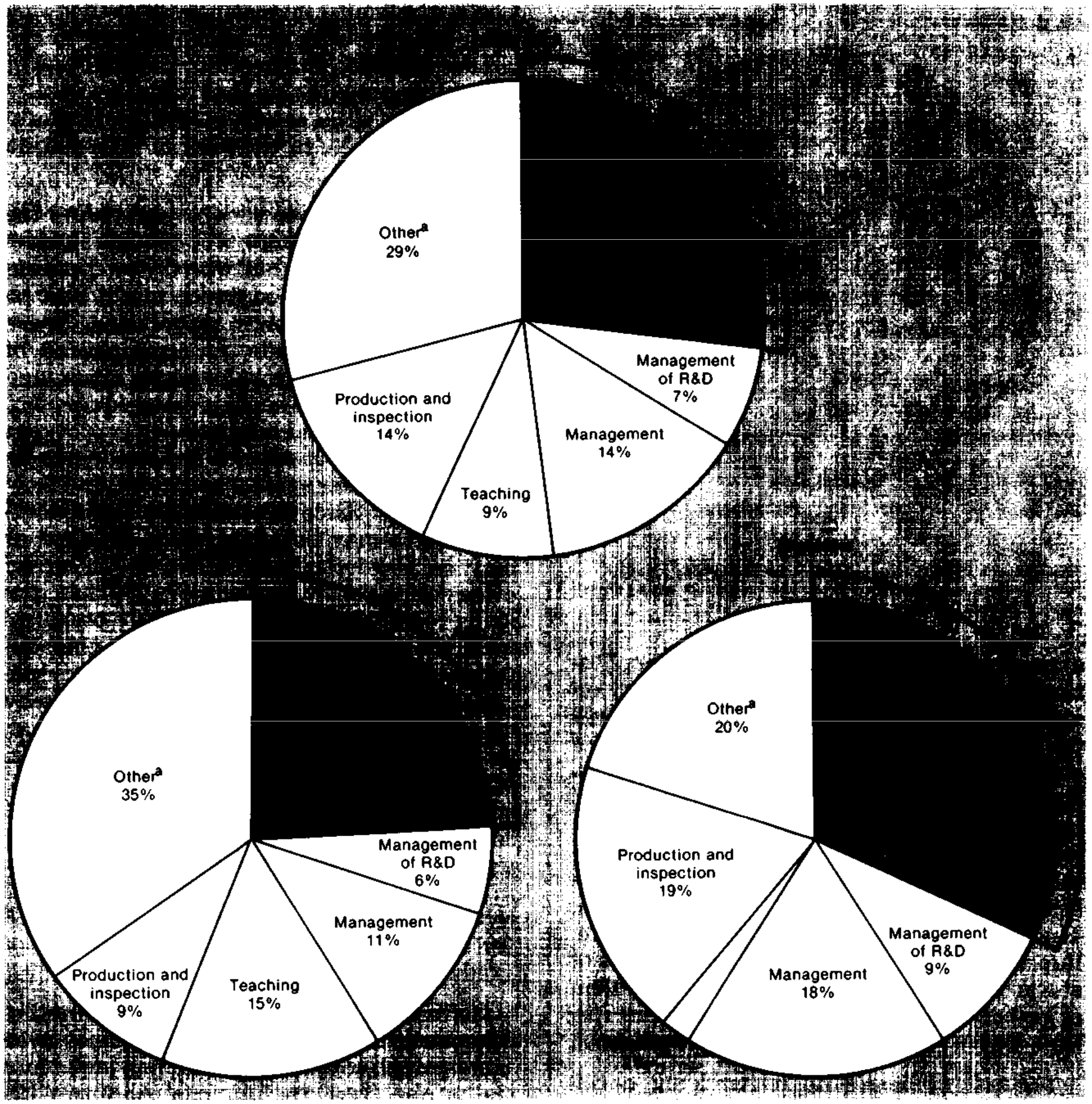
The task of identifying research and development workers in the field of information technology is complicated, moreover, by the fact that the traditional distinctions that have always been made between the tasks that are entailed in R&D and those entailed in production are becoming increasingly blurred in this area. This problem is clearly evident in the case of software engineering. Calculations of future manpower needs that focus specifically on R&D activities are, therefore, particularly difficult to make in the area of information technologies.

Questions also arise with respect to how the skilled technical workers, who provide support to the R&D process but who do not perform the most highly skilled tasks, might best be factored into manpower projections. These workers might include, for example, all of those who maintain, troubleshoot, repair, and sometimes fabricate sophisticated equipment, those who build and help develop prototypes of new products, draftsmen and nondegree designers, computer system operators, and technical writers. Since the skills that these workers require may be more easily obtained or may be more easily substituted—either by other workers or by technology-than the skills required for the more highly technical jobs, the manpower projections for this sector of the R&D process, and the policy implications that might be drawn from them, may also be quite distinct. Policies designed to affect the availability of skilled technical workers, for example, might call for some general educational changes at the elementary and/or secondary levels whereas those that are designed to influence the supply of manpower in a highly technical area such as artificial intelligence, or software engineering, might call for targeted incentives at the university or graduate studies level.

Defining R&D manpower and estimating manpower needs for this area becomes even more troublesome the further one looks into the future. Over the long run the future demand for manpower, for example, is likely to depend on the extent to which and the speed at which the new technologies are deployed throughout society. However, the rate and degree of their deployment will depend, in turn, on the kinds of social variables that are most often left out of forecasting models, and that are the most difficult to predict.

[11] Abbe Mowshowitz, "On Predicting R&D Skill Requirements for Information Technology," paper prepared for the Office of Technology Assessment, February 1984.

Figure 21.–Distribution of Scientists and Engineers by Primary Work Activity, 1981



[a]Includes reporting, statistical work and computing, consulting, other, and no report

SOURCE: *Science Indicators,* 1982.

Table 24.–Scientists and Engineers[a] Engaged in R&D Per Labor Force Population, By Country: 1963.82

Country	1965	1968	1972	1975	1979	1982
	S/Es[a] engaged in R&D per 10,000 labor force population					
France	21.0	26.4	28.1	29.3	31.6	NA
West Germany	22.7	26.2	36.0	41.0	47.7	NA
Japan	24.6	31.2	38.1	47.9	50.4	NA
United Kingdom	19.6	20.8	30.4	31.2	33.2[b]	NA
United States	64.1	66.9	57.9	55.5	57.9	63.8
U.S.S.R. (lowest)	44.8	53.5	66,5	78.2	84.4	89.8
U.S.S.R. (highest)	48.2	58.8	73.2	87.5	95.5	102.4
	S/Es[a] engaged in R&D (in thousands)					
France	42.8	54.7	61.2	65.3	72.9	NA
West Germany	61.0	68.0	96.0	103.9	122.0	NA
Japan	117.6	157.6	198.1	255.2	281.9	NA
United Kingdom	49.9	52,8	76.7	80.5	87.7[b]	NA
United States	494.5	550.4	518.3	532.7	620.2	716.9
U.S.S.R. (lowest)	521.8	650.8	862.5	1,061.8	1,216.4	1,340.4
U.S.S.R. (highest)	561.4	715.2	950.1	1,187.6	1,377.4	1,340.4
	Total labor force (in thousands)					
France	20,381	20,744	21,817	22,310	23,059	NA
West Germany	26,887	25,968	26,655	25,323	25,573	NA
Japan	47,870	50,610	51,940	53,230	55,960	NA
United Kingdom	25,498	25,378	25,195	25,798	26,464	NA
United States	77,178	82,272	89,483	95,955	107,050	112,383
U.S.S.R	116,494	121,716	129,722	135,767	144,201	149,215

[a]Includes all scientists and engineers engaged in R&D on a full-time equivalent basis (except for Japan whose data include persons Primarily employed in R&D excluding social scientists, and the United Kingdom whose data include only the Government and industry sectors)
[b]1978
NA—Not available.
SOURCE National Science Foundation, *Science Indicators 1982*

Future manpower requirements in software engineering, for example, might be significantly reduced as new software tools are developed and introduced, if new institutional practices are adopted to improve the efficiency of those working in the area, and if more and more applacations software are developed on personal computers by end users.[12] Predicting these changes or their future impacts is extremely difficult, given the newnessofthe field and the fact that they are dependent on a number of social variables-e.g., the willingness of individuals and institutions to both adopt and adapt to technological changes-variables that are themselves notoriously unpredictable.

[12] Ibid.

The Range of Manpower Predictions

Given the problems involved in identifying future manpower requirements, it is not surprising that there has been considerable controversy over and discrepancy between many of the projections that have been made about the need for high-technology manpower. Among those making forecasts, the consensus has been the greatest with respect to projected shortages of Ph.D.s to teach at the university level in the fields of engineering and computer science. To a somewhat lesser degree, manpower experts concur that the future growth in demand for computer scientists will be extraordinary. They disagree, however, about whether or not the educational system, as it exists today, can effectively respond to meet that demand. Agreement is lowest with regard to whether or not there will be a future shortage of engineers.

The following summary provides some sense of the range of projections. Because these forecasts are based on different assumptions, methodologies, baselines, and timeframes, it is impossible to compare and contrast them analytically as a whole. Evaluations about their reliability and accuracy are quite dependent, therefore, on judgments about the validity of their methods and assumptions.

Generally speaking, however, it can be said that manpower forecasts are more reliable the greater the number of and the more refined the underlying analysis.[13] The least sophisticated forecasting methodology, for example, might be one based solely on survey data, or simply extrapolating trends on the basis of the present. A much more comprehensive approach, on the other hand, might be one that takes into account such things as changes in the relative prices of capital and labor, and/or that posits a set of alternative assumptions about the future. The most ambitious forecasts are those that try to factor into their analysis the impact of technological change.[14]

Perhaps the most widely referred to, and among the more sophisticated projections, are those that have been put forward by the Bureau of Labor Statistics (BLS). These projections cover a period of 10 to 15 years. They are not only based on a set of alternative economic scenarios, positing different rates of growth; to some extent, they also seek to take technological change into account. Moreover, BLS has consistently sought to improve its methodology by systematically evaluating the accuracy of its own projections. Such evaluations show that BLS has had more success in determining how technology might effect future job growth than it has in identifying at what point such changes in employment patterns might take place. Past projections have, moreover, tended to exaggerate the growth of technical occupations and underestimate the decline of certain traditional jobs. One useful measure of the accuracy of these projections is the recent finding that 60 percent of the 1980 forecasts fell within a 10 percent range of the actual employment level for that year.[15]

BLS projects the rate of growth and the future demand for manpower in given occupational categories. The Bureau's most recent projections for those categories most relevant to information technology are listed in table 25.[16] For each category, there are three projections—high, medium, and low—each corresponding to one of the three economic scenarios used by BLS in developing their forecasts.

Because it does not make predictions about the future supply of manpower, the Bureau of Labor Statistics does not predict labor shortages or labor surpluses per se. However, review of the recent articles in the BLS publication, *Occupational Outlook Handbook*, suggests that there will be a multi-tiered mar-

Table 25.—BLS Manpower Estimates

Base year: 1982	1995	
Electrical and electronic engineers:		
320,000	Low	531,000
	Moderate	528,000
	High	540,000
Computer specialists:		
Programmers:		
226,000	Low	465,000
	Moderate	471,000
	High	480,000
Systems analysts:		
254,000	Low	469,000
	Moderate	471,000
	High	480,000
Technicians:		
55,000	Low	106,000
	Moderate	108,000
	High	108,000
Computer operators:		
211,000	Low	366,000
	Moderates	371,000
	High	378,000

SOURCE: Tom Nardone, Manpower Economist, Bureau of Labor Statistics, Department of Commerce, personal communication, May 15, 19S4.

[13] Henry M. Levin and Russell W. Rumberger, *The Educational Implications of High Technology*, The National Institute of Education Report #83-A4, 1983.
[14] Ibid.
[15] Ibid.
[16] Conversation with Tom Nardone, Manpower Economist, Bureau of Labor Statistics, Department of Commerce, May 15, 1984.

ket for these job categories, with a shortage of people with some specific skills and a surplus of those with others.

The National Science Foundation also makes projections of the supply and demand for scientific, engineering, and technical personnel. These projections are developed using a multistep model, similar to the one used by BLS. Like the BLS model, for example, the NSF model tries to anticipate how technological change might affect future manpower needs. In one way, however, the NSF model goes further than that of BLS: its alternative scenarios posit different levels of defense spending as well as different levels of economic growth.[17]

In its recent report, Science *Indicators 1982,* NSF pointed out that computer specialists accounted for almost 45 percent of the total growth of scientific employment over the period 1976-81. Matching this growth against the future supply of computer science personnel, it predicted a future shortage in this area. Indicators for the future supply and demand of engineers were more mixed, however. For while these indicators revealed a shortage in 1981, they also suggested that by mid to late 1982, the situation already appeared to be shifting back towards a balance between the supply of and the demand for engineers in general.

A recent survey conducted for NSF raises some questions about the degree to which manpower shortages may in fact materialize in the future, even in the area of computer science. Nearly one half of the 351 firms surveyed, for example, reported fewer openings for scientists, engineers, and technicians during the 1982-83 recruiting year than in the 1981-82 period. These results are broken down by area in the following figure[18] (fig. 22).

Focusing on manpower needs for defense, the U.S. Air Force, in *The Regional Planning and Evaluations Systems (ROPES)* Project, forecast manpower needs for 30 States and 70 major cities. The States were selected for analysis because they are major centers of defense activity. The ROPES study found that the need for all skill groups involved in "the use, operation and repair of computer equipment will grow at an alarming rate throughout the 1980s and that these skills will be particularly affected by increased expenditures for defense. " Although the Air Force study group did not project the supply of manpower for these areas, they concluded, based on the projected rate of growth in demand, that the field of computer science, and perhaps electrical and mechanical engineering, may be areas of potential national shortage.

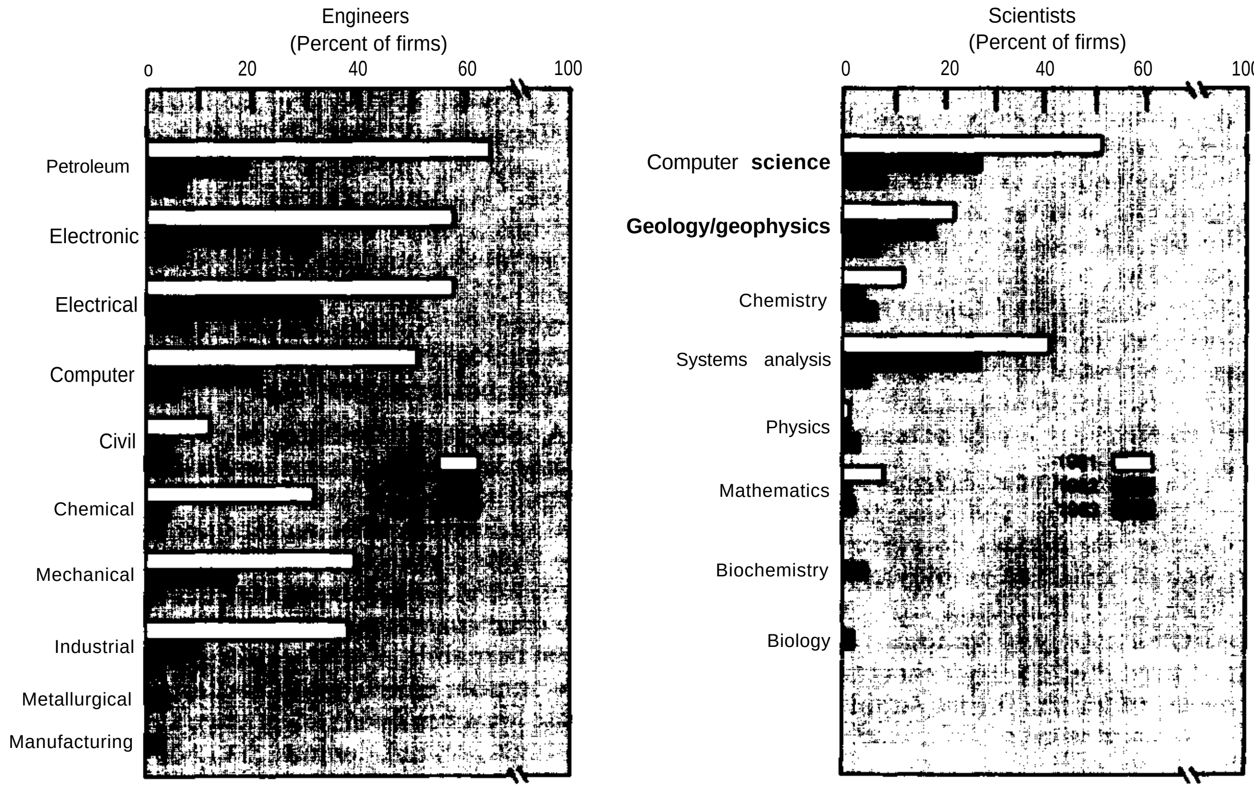
A 1982 study by Betty M. Vetter of the *Scientific Manpower Commission* summarizes information on the present and future supply and utilization of scientists and engineers in the United States. Vetter concludes that, except in the field of computer science, the supply of scientists appears sufficient to fill near-term demands. For engineers, she notes that the number of new graduates at the baccalaureate level has been rising since 1975, but that "a high level of demand has not only fueled that increase, but has utilized so many engineering graduates at the baccalaureate level that graduate enrollments of U.S. students have not climbed commensurately and shortages of Ph.D. engineers have become serious, at least at academic institutions. " She concludes, however, that there is no general agreement about the adequacy of the future supply of engineers, even when considering particular specialties.

Industry projections of future manpower needs are quite inconsistent with one another. Derived, as they are, by stakeholders, their conclusions must be regarded with some degree of caution.

Basing its conclusions on a survey of 815 manufacturing facilities, the American Electronic Association (AEA) predicts that through 1987, the need for technical professionals will grow by 69 percent; while the need for technical paraprofessionals will increase by 60 percent. Respondents to their survey estimate, moreover, that in 5 years they will need to

[17] Levin and Rumberger, op. cit., pp. 12-13.
[18] Ibid.

Figure 22.—Percentage of Firms Reporting Available Jobs for Scientists and Engineers



SOURCE: National Science Foundation.

employ more than 100,000 each of new technical professionals and new technical paraprofessionals.[19] The occupational groups for which they foresee a tremendous amount of growth during this period—defined as over 100 percent total increase—are software engineers, electronic engineering technologists, and computer analysts/programmers.[20]

To project the future supply of these key occupational groups, AEA uses data that assume that U.S. colleges will continue to increase the number of Bachelor of Science/ Computer Science degrees at the same rate as they have over the past 5 years. Comparing projected supply and demand, the AEA report concludes that by 1987 there will be a shortage of 113,406 computer scientists and electrical engineers. Discounting employment related to defense, the shortage would be 81,780.

More skeptical about the likelihood of an impending shortage of electrical engineers is David Lewis, Council Chairman for the Career Activities Council of the Institute of Electrical and Electronic Engineers, Inc. (IEEE). Noting that the engineering profession is made up of people who are trained in a range of disciplines, projections of shortages, he says, fail to take into account the extent to which electrical engineers can be substituted for by engineers trained in other specialties. He has expressed concern, moreover, that an uncritical acceptance of such predictions might lead to a surplus of electrical engineers, a situation not dissimilar to the one that existed for aeronautical engineers in the early 1970s.[21]

[19] AEA, p. 10.
[20] Ibid.
[21] Ibid.

The Supply of Manpower

Although manpower projections tell us something about the number of people who will be needed and who may appear to fill existing high-technology positions, they say very little about the quality of skills and experience that the people who are available might bring to these jobs. To evaluate the quality of our existing and future supply of manpower for R&D in information technologies, we have to look at the major source of this manpower—at the Nation's educational institutions.

Formal educational institutions are, of course, neither the only nor necessarily the most significant institutional setting for manpower training and development. At one point in history, for example, it was the family that dominated in preparing its members for economic roles. Later, as society became more technologically advanced, a somewhat more formal system of apprenticeship emerged. Formal schooling became especially important during the age of industrialization.

Today, as we move towards what has been characterized as a high-technology society, businesses have themselves become involved, both formally and informally, in performing educational tasks. This has been particularly true in the area of information technology, where the larger corporations like IBM, Xerox, and Digital Equipment Corp. have set up their own educational centers. Moreover, informal training takes place and is diffused within the business community as people, trained in large companies, move on to form new companies of their own.

Recognizing that a number of different kinds of institutions are presently involved in the development and training of future manpower, this chapter will nonetheless focus on those that are a part of the formal educational system. For it is chiefly within the context of these institutions that the Federal Government plays out its role in manpower development.

The Problems in Higher Education

While the American university system has always been renowned for the number of scholars and the amount and quality of research that it has generated, today many people are beginning to question whether universities can continue to effectively perform all of their traditional roles. And, although almost all areas of university education have suffered from the problems of increased educational responsibilities and increased educational costs, the problems that universities face appear to be particularly acute in the areas that generate manpower to perform R&Din information technologies. University departments in these areas are having an especially difficult time because, given their limited funding, they are finding it almost impossible to compete for manpower and other resources in what is becoming a rapidly growing and wide-open high-technology market.

The difficulties are well illustrated in the case of engineering and computer science education, where a large proportion of faculty positions are unfilled and where the number of Ph.D.s graduating each year has dropped substantially. The problem in this area is not one of attracting highly qualified undergraduate students.[22] Over the past decade undergraduate enrollments in these areas have grown at a tremendous rate—by 80 percent in the case of engineering[29] and by 20 percent in

[22] Jeanne McDermott, "Technical Education: The Quiet Crisis," *High Technology*, November/December 1982, p. 87.
[23] Jerrier A. Haddad, "Key Issues in U.S. Engineering Education, " *NAE Bridge*, summer 1983, p. 11.

the area of computer science.[24] And, given the growing popularity of electrical engineering and computer science and the limitations that, in almost all engineering schools and departments of computer science, are now being placed on the number of admissions, the high qualifications of new entrants are without precedent.[25]

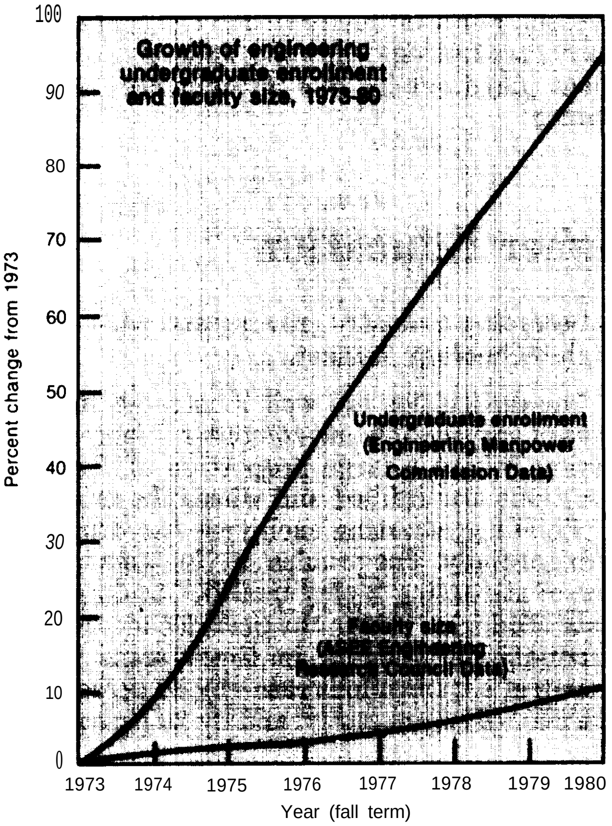
Rather, as figure 23 illustrates, the problem at universities-has been one of recruiting sufficient faculty members to support this enrollment. According to the American Council on Education, 1,583 teaching positions were vacant in the Nation's 244 accredited departments of engineering during the 1980-81 academic year.[26]

The gap would probably be much greater, moreover, were it not for the sizable number of foreign engineers who teach in American colleges and universities. A recent survey of engineering schools found, for example, that 25 percent of all junior faculty members in engineering received their bachelor's degree outside of the United States.[27]

The shortage of faculty members in the field of engineering and computer science has been attributed to the fact that industry, by offering higher salaries and other, nonmonetary incentives, has been able to draw a number of academics and students away from universities.[28] The extent of the problem is illustrated by figure 24, which shows that, in contrast to other areas of science, only a relatively small proportion of the Nation's engineers and computer scientists are employed in academia.[29]

Discrepancies between the salaries earned by scientists working in industry and academia have, in fact, been quite extensive. It has not been atypical, for example, for an inexperienced electrical engineer with a bachelor's degree to earn more than an assistant professor of engineering with a Ph.D.[30]

Figure 23.—Comparison of Growth in Engineering Undergraduate Enrollment and Number of Faculty, 1973-80



NOTE: Faculty numbers drawn from ASEE's Research and Graduate Study directory were adjusted on the basis of enrollment data to include the same number of schools as in EMC'S enrollment survey.

SOURCE: *Engineering Education,* November 1982.

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[24] "AS Students Flock to Computer Science Courses, Colleges Scramble To Find Professors," *The Chronicle of Higher Education,* Feb. 9, 1981.

[25] John Horgan, "Technology '84 Education," *IEEE Spectrum,* January 1984. [Data on Admission Illustrations.]

[26] "As Students Flock to Computer Sciences Courses," op. cit.

[27] "As Students Flock to Computer Science Courses," op. cit.

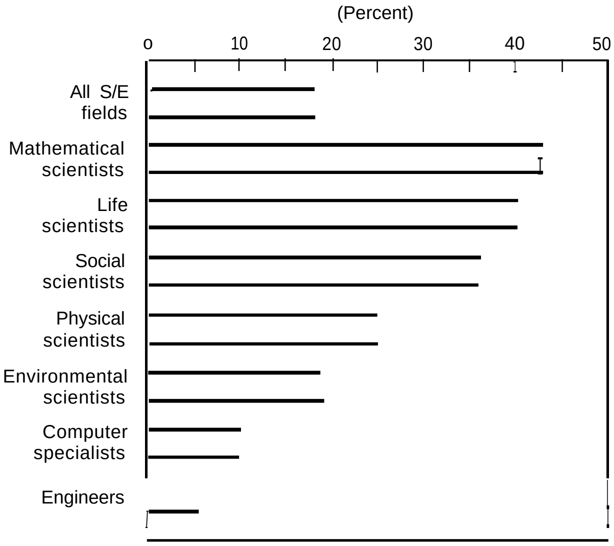
[28] " Supply of Engineering Faculty," *Electronic Market Trends,* January 1982, p. 14:

> It should be noted in this regard that the continued supply of foreign faculty will depend to some extent on the fate of The Immigration Reform and Control Act, a bill that was recently passed by the Senate and that would require foreigners to return home after graduation for at least 2 years. An amendment maybe attached to the bill, however, allowing certain students studying in high-technology fields to stay.

[29] *Science Indicators,* op. cit., p. 123.

[30] McDermott, op. cit., p. 47.

Figure 24.—Share of All S/Es Employed in Educational Institutions by Field, 1981



SOURCE: *Science Indicators, 1982.*

university campuses to industry is the poor condition of most university research facilities. In an effort to reduce costs, for example, many colleges and universities have failed to purchase, maintain, and upgrade their buildings and equipment. As a result of such decisions, university instrumentation inventories are now nearly twice as old as those of leading commercial labs.[31] The cost of adequately improving these facilities in the area of engineering education alone has been estimated to be, at a minimum, between $1¼ billion to $2 billion.[32] This cost, moreover, is rapidly escalating with inflation.

Problems of university instrumentation are particularly serious in those fields where the cost of equipment is especially high and where it plays an essential, if not an integral, part of the educational and research processes themselves. This is the case, for example, in the area of artificial intelligence. Only very few universities can afford the cost or have the space and facilities available to house and support the kinds of sophisticated equipment required to perform R&D at the leading edge of the field.[33]

Other institutional factors that have been cited as reasons for the exodus from academia to industry include uncertainty of tenure, heavy teaching loads, inadequate funds and institutional support for research, and increases in educational fees compounded by diminishing financial aid for students.

It is difficult to assess the extent to which these problems will persist in the future. The number of students studying for Ph.D.s in engineering significantly decreased over the course of the decade 1972-82. Educators of engineering suggest that, as a result, there will not be enough new faculty members to replace even those who die or retire.[34] If this kind of trend continues, there will probably be a faculty shortage in the future. However, there are some indicators that point to a reversal of this trend. In 1982, for example, the number of engineers earning doctorates increased for the first time in 8 years.[35] In 1983, the number increased again—from 2,888 to 3,023.[36]

On the other hand, the academic manpower problem may be more difficult to overcome in the field of computer science where the percentage of faculty leaving for industry is two times that of any other field of engineering.[37] Even in this area, however, there is some anecdotal evidence reported by NSF to suggest that the number of graduate students studying in this area is now increasing.[38]

It is possible, however, that faculty shortages could become even more critical in the future in some specific areas, limiting the amount of research and the amount of teaching that can be done in these fields. This is particularly true, for example, in an area such as artificial intelligence (AI).[39] Because the field

[31] John Brademas, "Graduate Education: Signs of Trouble," *Science*, vol. 223, Mar. 2, 1984, p. 881.
[32] Haddad, op. cit.

[33] *OTA Case Study on Artificial Intelligence.*
[34] NAE Bridge, op. cit., p. 121.
[35] *Science Indicators*, op. cit., p. 123.
[36] *Manpower Comments*, vol. 21, No. 3, April 1984, p. 24.
[37] Curtis, op. cit., p. 8.
[38] Conversation with Kent Curtis, National Science Foundation.
[39] *OTA Case Study on Artificial Intelligence.*

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of AI is so specialized and because the size of the research community is so small to begin with, the number of qualified faculty members cannot be multiplied rapidly enough to meet the rising number of students who are now beginning to enter the field. The problem is likely to worsen if, as might reasonably be expected, the greater commercialization of AI applications together with enhanced military interest in the field lead to increased competition for those trained in artificial intelligence in the future. The effect of a faculty shortage may be particularly acute in an area such as this where the required skills and knowledge are best taught in an apprenticeship-type situation.

To alleviate the present faculty shortage, more than half of all engineering colleges have had to eliminate courses, and two-thirds are increasingly substituting graduate assistants for full professors for some coursework, a situation that could adversely affect the teaching of advanced technical courses. A number of universities have also increased the teaching load.[40] It has been estimated, for example, that over the past 10 years the teaching burden of the average professor of engineering has increased by 40 percent.[41] While such actions may ameliorate the problem in the short term, in the long term they may—to the extent that they discourage people from pursuing teaching careers-actually exacerbate it.

Compounding their problems of loss of faculty and deterioration of equipment, schools of engineering and departments of computer science will also have to find ways to modernize their curricula to meet the educational needs of a high-technology society undergoing rapid technological change. It has been estimated, for example, that given the speed at which technological change is occurring, today's engineering education, acquired over the course of 4 or 5 years, will be obsolete in about the same amount of time.[42] Up-to-date coursework, moreover, will have to take into account the changing style of doing engineering and computer science. To be effective, for example, the engineers and computer scientists of the future may have to be adept in communications as well as in technical skills.[43] As one young computer scientist described it,

> The old stereotype of an engineer was a guy with a slide rule hooked to his belt and who was not into sports, not into team play.
>
> The jobs that we have to do now are not 1-man year projects but are 5- to 10- to 20-man-year projects. Integrated circuits, even linear ICs, are so complex that they are no longer designed by one engineer, but by teams. . . this concept may be new to us, but it's not to the Japanese.

The mounting problems that engineering schools are facing would appear to be having a negative effect on the quality of education that they provide. In the last 3 years, for example, 30 percent fewer engineering schools were given full 6-year accreditation. Moreover, there has been an increase of over 70 percent in the number of institutions that have been asked to show cause why their accreditation should not be revoked.[44] Many university officials agree with this assessment. In a survey of engineering colleges conducted by the American Council of Education, 49 percent of the respondents reported that the quality of education provided by their institutions had either greatly or moderately declined.[45] Concerns about the decline in the quality of engineering education are also echoed in the industrial community, where a number of companies have independently taken steps to improve the pool of engineering manpower.[46]

The current situation is not, however, set in stone. To the contrary, the American educational system is today in the midst of considerable change. In adopting policies to affect the future supply of manpower, therefore, policymakers should be reminded of the "pendulum effect." In making decisions about the fu-

[40] McDermott, op. cit., p. 90.
[41] *Infoworld,* May 30, 1983, p. 32.
[42] "The Changing Face of Engineering," *Electronics,* May 31, 1983, p. 127.
[43] Ibid., pp. 127-128.
[44] McDermott, op. cit., p. 90.
[45] *High Technology Manpower in the West: Strategies for Action,* op. cit., p. 12.
[46] For a discussion of many of these efforts see *Chapter 6: New Roles for Universities in Information Technology R&D.*

ture, they need to take into account not only the projections of future manpower needs but also how present reactions to those projections may, in fact, undermine their validity.

Concerned about the present state of high-technology manpower training in the United States, a number of businesses and corporations, for example, have already taken it upon themselves to improve the situation. In particular, they have adopted a number of measures that are designed to keep faculty in academia and to encourage students to pursue academic careers. Bell Labs has recently begun a program that, over time, will provide $2 million to doctoral candidates studying in fields related to telecommunications. The General Electric Co. has donated $2 million to engineering schools to be used primarily by teachers and Ph.D. candidates. IBM has established 150 graduate and postdoctorate fellowships in engineering, computer science, and information systems. And Hewlett-Packard recently initiated a student loan forgiveness program that allows students to write off a part of their loans in accordance with a prearranged schedule for each year that they teach.

Companies are also providing funds for equipment and instrumentation. Digital Equipment Corp. and IBM together have donated *$50* million for equipment to MIT. Sizable contributions have also been made to a number of other universities by IBM, Hewlett-Packard, Apple Computer Inc., Wang Laboratories, Inc., NCR Corp., and Honeywell, Inc. (see fig. *25).*

In addition, businesses and corporations are, more and more, joining with universities in cooperative ventures to overcome perceived shortages of scientific and technical manpower. The goal of training manpower, for example, was the major reason for establishing the Microelectronics and Information Sciences Center at the University of Minnesota, and the most important inducement in gaining industry support. These cooperative ventures, as well as a number of others, are discussed in some detail below, in chapter 6.

Figure 25.—Educational Gifts by Computer Vendors

IBM	$50 million in cash and equipmen to 20 universities to advance research in CADICAM. • Co-donation of $50 million in equipment to MIT to research data transfer. • $15 million pledge to Brown University to establish institute for research in information and scholarship. • $2.4 million in graduation fellowships to science and engineering students.
Digital Equipment Corp.	• $ co-donation of $50 million in equipment to MIT. • $1.6 million to Boston University to fund new compute science programs. • Total of $45 million in fiscal 1982 to higher education.
Apple computer, Inc.	• $21 million in equipment to California schools grades K-12 for "Kids Can't Wait" Program. Company wants a Similar nationwide program, but wants Federal tax deductibility first via so-called "Apple Bill" • $500,000 to Brown University in form of 5O Lisa Computer.
Hewiett-Packard co.	• Approximately $22 million, mostly in equipment, to universities in fiscal 1983.
Wang Laboratories, inc.	• Total of $3.7 million in equipment and $458,000 in cash to 23 universities and secondary schools in 1982.
NCR Corp.	• $140,000 in equipment to Michigan State University. • $170,000 in equipment to Cornell University. • Several gifts of companies NCR systems to other universities.
Honeywell, Inc.	• S220,000 to Arizona State University. • $30,000 to United Negro College Fund. • Total of $3 million in education contributions in 1982.

SOURCE: Compurerworld, July 25, 1983.

The States have also taken steps to improve and foster the development of manpower for a knowledge-intensive society. Not only have they joined in cooperative ventures between industry and the universities, they have also taken steps to enhance the research environment and to improve faculty salaries.

While most State and corporate efforts to improve manpower training have been focused on the most prestigious universities, there have been a number that have sought to improve the education and training provided to less advantaged colleges and universities. Exxon, for example, recently donated $1.8 million to six predominantly black engineering colleges, to be spent during the course of the next 3 years. IBM has lent several of its employees to teach in schools that serve "disadvantaged students. "

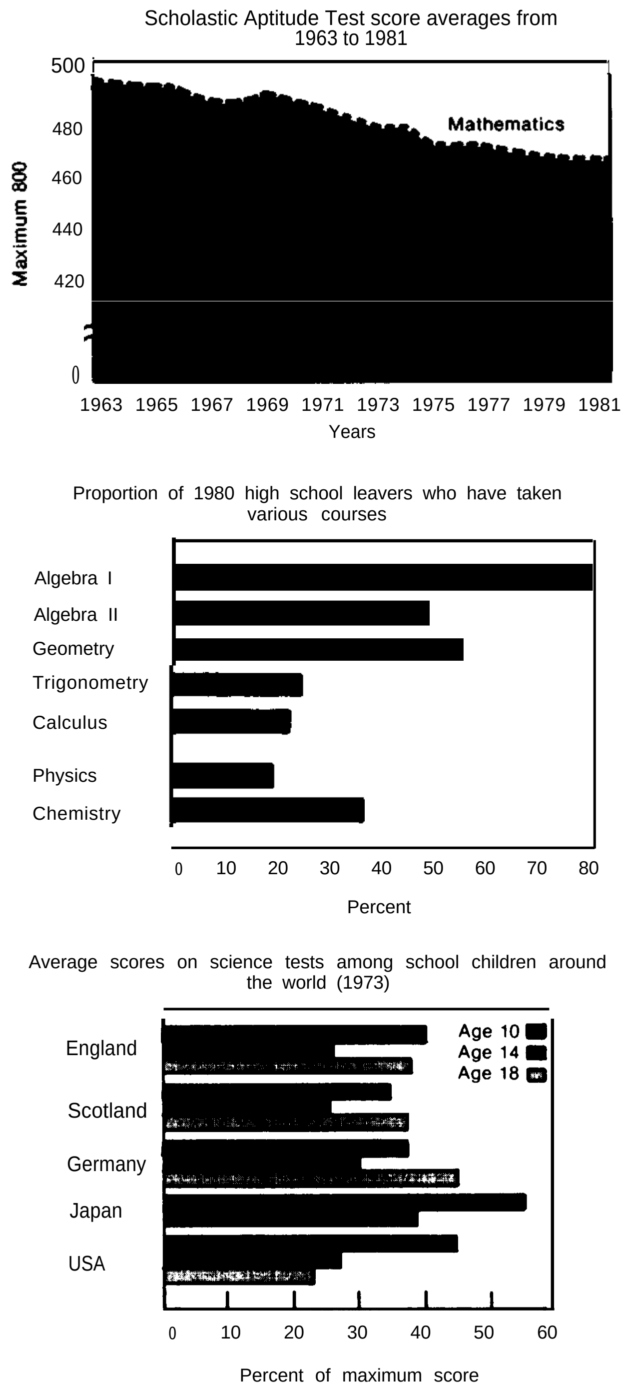
Elementary and Secondary Education

To determine whether or not there will be enough highly qualified people available to perform R&D in information technology, one must look not only at institutions of higher education, but also at elementary and secondary schools. Generating the pool of students from which university and graduate students are drawn, these institutions have an effect on both the number and the quality of students who desire to pursue fields of study that might lead to work in this area.

A number of reports have been released recently that raise serious questions about the ability of elementary and secondary schools in the United States to adequately prepare the Nation's youth to work in a knowledge-intensive society. While differing in the focus of their concerns, all of these reports find that our schools are inadequately preparing American students for their futures. As evidence, they point to declining test scores, the need for colleges and business to provide remedial education and training programs, the level of functional illiteracy among the general population and the Nation's poor showing in international comparisons of student achievement.[47]

Of particular concern in all of these studies is the overall poor quality of math and science education. A number of indicators give cause for such concern (see fig. 26). Enrollments in math and science courses, for example, are generally low. Only one-third of all U.S. high school graduates have completed 3 years of mathematics, and less than 8 percent have completed a calculus course.[48] Moreover, in grades kindergarten through six, students spent only approximately 20 minutes per day on science lessons. And by 10th grade, only about half of all students study any science

Figure 26.—Selected Indicators of the Overall Quality of Mathematics and Science Education in the United States



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[47] James B. Stedman, *Education in America: Reports on Its Condition and Recommendations for Change*, Issue Brief # IB83106 Congressional Research Service, Library of Congress, Nov. 17, 1983.

[48] Michael Heylin, "High School Science Problems Gain Spotlight," *Chemical & Engineering News*, May 24, 1982, p. 39.

at all.[49] In contrast, students in many other industrialized countries spend about three times more class time on math and science than the most scientifically oriented American student.[50]

Student attitudes about science and math also reflect problems in the education of these courses at the elementary and secondary school levels. Science, for example, is the subject that is preferred the least by most American students.[51] Moreover, although most children regard scientists themselves as being intelligent and dedicated, they consider the work that scientists do as being "boring, dull, and monotonous. "[52] Mathematics is not much more popular. While it is the favorite subject of 45 percent of students in the third grade, it is rated tops by only 18 percent of those in the 12th.[53]

Overall, student performance in these areas reflects the lack of interest and low enrollment in these subjects. In the three studies conducted by the National Assessment of Educational Progress, which were designed to assess the achievements of precollege students in a number of areas over the years 1969, 1973, and 1977, all age groups showed significant average declines on mathematical applications which involve the use of mathematical knowledge, skills, and understanding to solve problems.[54] In the area of science, the results were similar. There was a downward trend for all age groups, from the first to the second assessment, although this decline appeared to be diminishing for 9 and 13 year olds in the third assessment.[55]

As in the case of higher education, many of the problems in precollege math and science education have been attributed to the shortage of high-quality teachers to teach in these areas. According to the Director of the National Science Teachers Association, since 1971 there has been a dramatic decline in the number of people training to teach in these areas—79 percent in the case of math and 64 percent in the case of science (see fig. 27).

The lack of new entrants into the teaching profession is not surprising insofar as there are few incentives to draw well-qualified individuals into the field.[56] With the financial problems facing schools today, a career in teaching is no longer considered to be secure. And it is considered by many to be less likely to provide the rewards of public status or personal esteem. Since teaching salaries are by no means competitive with those in private industry, many of the most qualified teachers—especially those with training in math and science—are giving up teaching to sell their skills on the open market. Moreover, well-qualified women–a traditional source of high-quality educators—are particularly likely to seek out the wider range of employment opportunities now available to them.[57]

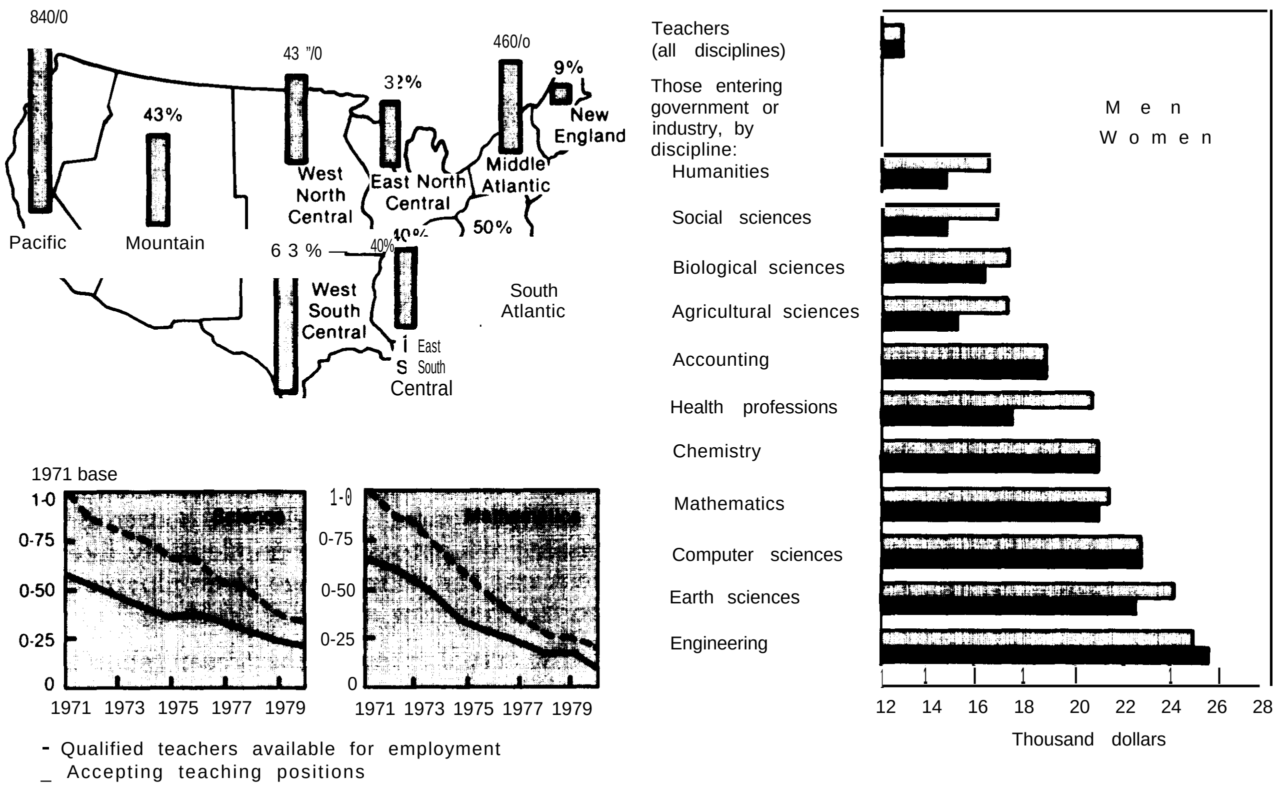
The actual extent of the present shortage of qualified math and science teachers is a matter of some debate, however. A survey of educational placement offices conducted by the National Science Teachers Association found, for example, that no less than one-half of the Nation's math and science teachers were hired on an emergency basis.[58] The Association for School, College and University Staffing has reported, moreover, that there is a considerable nationwide shortage of teachers in the area of mathematics, physics, and computer programming on the other hand, a recent study conducted by the General Accounting Office concluded that the gaps in the available

[49]Herbert J. Walberg, "Scientific Literacy and Economic Productivity in International Perspective, " *Daedalus*, p. 12.
[50]Heylin, op. cit.
[51]Walberg, op. cit.
[52]Heylin, op. cit.
[53]Walberg, op. cit.
[54]*Science Indicators*, op. cit., p. 74.
[55]Ibid.

[56]*The New Scientist*, July 14, 1983.
In explaining the shortage of teachers, much of the attention has focused on salary differentials between teaching and industry. While salary levels are no doubt important, one recent study found that internal morale factors, such as the potential for personal growth, are even more so. Edward B. Fiske "Teacher Fulfillment Put Above Pay, " *The New York Times*, Oct. 4, 1983, p. C1.
[57]J. Myron Atkin, "Who Will Teach in High School?" *America Schools: Public and Private*, Daedalus, summer 1981.
[58]*The New Scientist*, op. cit.
[59]*Teacher Supply/Demand 1984*, Association for School, College, and University Staffing.

Figure 27.—America% Science Teacher Shortage

A 1982 survey reveals just how many new science and mathematics teachers in the U.S. do not hold the appropriate qualifications to do their jobs. This is partly a result of a fall in the numbers of those achieving the appropriate qualifications. Another important factor is the far **more attractive salaries offered to graduates in the sciences,** whether qualified teachers or not.



Teachers taken on in 1982 to teach science and math not qualified in those subjects (top left). Decline in number of new teachers between 1971 and 1980 (above left). Starting salarlis for new graduates entering careers in government or Industry in 1982 (above r!ght).

SOURCE: New Scientist, July 14, 1963.

information are so great that whether or not there are shortages of math and science teachers, and whether or not the quality of technical teaching has declined in recent years, cannot be determined.[60]

Since a strong foundation in math and science is, in most cases, essential to a future career in information technology R&D, these findings raise a number of questions about the future supply of manpower in this area. Their answer, however, is not particularly clear or straightforward. For although the data show that the level of math and science understanding and competency for the student population as a whole has declined, it has not declined among those students who are most likely to pursue careers requiring a strong background in math and Science. [61]University math and science departments and schools of engineering report, moreover, that they are continuing to recruit high-quality students, many of whom are being drawn from the humanities departments with the idea of having better future job prospects[62] (see, e.g., fig. 28). On the other hand, given the diminishing supply of high-quality educators in these fields and the predicted decline in the school age popula-

[60] *New Directions for Federal Programs to Aid Mathematics and Science Teaching,* GAO/PEMD-84-5, Mar. 6, 1984.

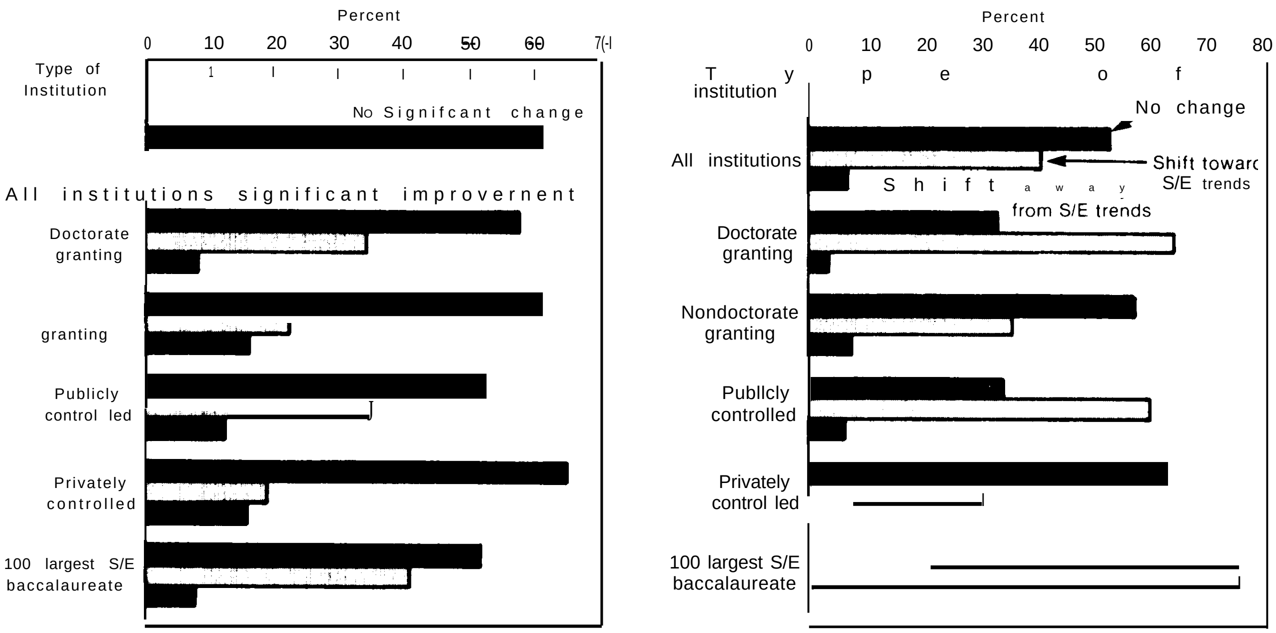
[61] *Science Indicators,* op. cit., p. 77.

[62] Frank J. Atelsek, *Student Quality in the Sciences and Engineering: Opinion of Sam"or Academic Officials,* Higher Education Panel Report No. 58, American Council on Education, February 1984.

Figure 28.—Selected Indicators of Shifts in Undergraduate Science/Engineering Education

Chart 1. Perceptions of academic officials about change over last five years In quality of undergraduate science/engineering (S/E) students, 1982

Chart 2. Opinions of academic officials about shift in distribution of most able undergraduate students between science/engineering (S/E) and other fields over the last five years, 1982



SOURCE: National Science Foundation and American Council on Education,

tion,[63] a more serious problem may emerge in the future.

Just as the situation in the case of higher education, the situation in elementary and secondary education is not static and changes are taking place that might affect the long-term supply of scientific and technical manpower. The public's response to the numerous reports on the condition of American education has been immediate and widespread, involving parents, teachers, businessmen, and government officials at all levels.

[63] The number of Americans graduating from high school is projected to drop from a peak of 3.2 million of 1977 to a low of 2.3 million in 1992, following a roller coaster pattern through the end of the century. *High School Graduates: Projections for the Fifty States (1982-2000)*, Western Interstate Commission for Higher Education, Boulder, CO.

The Federal Role in Manpower Development

As the largest employer of scientists and engineers, the Federal Government has a direct interest in whether or not the educational system can provide an adequate supply of technically trained people. Its role in the development of manpower, however, has traditionally been indirect. For it is the States, and not the Federal Government, that have had the primary responsibility for educational policies.

Given the Constitutional limitations on the Federal Government's role in education, the responsibility for developing manpower has always been shared by a number of different social institutions ranging from the family to the business community. As American society has become more technologically advanced, however, the Federal Government has been increasingly called onto play a more significant role. Pressure on it to be more active in this area is particularly strong today, as the Nation seeks to maintain its place in a highly technical and competitive world environment.

While conscious of the economic benefits associated with having a skilled labor force, Americans did not originally adopt a formal system for transmitting vocational and technical skills, in the earliest years of their history, when agriculture was the dominant mode of production.[64] Instead, most formal educational institutions were designed to serve general social and political functions, while general vocational skills were left to be passed on more or less informally, by family members or through apprenticeship systems.[65]

In particular, there was little effort given to, or even much concern for, the development of scientifically trained manpower. When scientists were needed in the United States, they were brought over from Europe. Thus, it was only in 1902 that the Federal Government first became involved in the development of scientific manpower. Concerned at this time about the security dangers entailed in relying almost exclusively on foreigners for scientific expertise, Congress established the Army Corps of Engineers at West Point.[66]

It was only with the rapid industrialization of society, at the end of the century, that education came to be really valued in economic and technical terms.[67] And then, as Americans came to believe that special technical knowledge was the key to prosperity in the modern age, secondary educational institutions were restructured to prepare American youth for an increasingly differentiated set of economic roles. Not only were vocational courses added to the educational curriculum, but the schools themselves were remodeled to conform to the prevailing business standards of efficiency. The business community played a major role in bringing about these changes. Concerned about strikes, labor turnover, and increasing worker absenteeism, they hoped that schooling would socialize a growing number of immigrant youths for the workplace.[68 69]

The growing enthusiasm for scientific and technical knowledge also had an impact on the nature of higher education. Accustomed to training gentlemen as preachers, lawyers, and doctors, the universities began to expand their roles and to train people in the more vocational applications of education.[70] Efforts to move in this direction met with considerable resistance from traditional academics, however, who were disdainful of the study of experimental science and even more so of the teaching of the "useful arts."[71 72]

The transformation of the university system was greatly facilitated by the passage of Federal legislation establishing the land grant colleges. Provided for under the Merrill Act of 1862,[73] these colleges, open to children of all backgrounds, were established to provide education in practical fields such as agriculture, engineering, home economics, and business

[64]For a discussion of American education in the preindustrial period, see Bernard Bailyn, *Education in the Forming of American Society* (New York: W. W. North, 1980); Lawrence Cremin, *Traditions in American Education* (New York: Basic Books, Harper, 1976); and Rush Welter, *Popular Education and Democratic Thought in America* (New York: Columbia University Press, 1962).

[65]A. Hunter Dupree, *Science in the Federal Government: History of Policies and Activities to 1940* (Cambridge, MA: Belknap Press of Harvard University Press, 1957).

[66]Ibid. Initially trained in the skills necessary to carry out explorations of the West and to conduct surveys of the eastern coastline, these West Point graduates played a key role in many of the scientific ventures carried out by the Federal Government up until the end of the 19th century.

[67]David K. Cohen and Barbara Newfeld, "The Failure of High Schools and the Progress of Education," *America's Schools: Public and Private*, Daedalus, spring 1981.

[68]David Tyack and Elizabeth Hansot, "Conflict and Consensus in American Education," *America's Schools: Public and Private*, Daedalus, summer 1981.

[69]Ibid.

[70]Ernest L. Boyer and Fred Heckinger, *Higher Education in the Nation's Service* (Washington, DC: Carnegie Foundation for the Advancement of Teaching, 1981); and Edward Shils, "The Order of Learning in the United States From 1865-1920," *Minerva*, vol. 21. No. 2, summer 1978.

[71]David Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism* (New York: Alfred A. Knopf, 1977), p. 24.

[72]Boyer and Hechinger, op. cit.; and Shils, op. cit.

[73]This law provided land to the States, the proceeds of which were to be used to teach in the fields of agriculture and mechanical arts. Subsequent legislation provided Federal financial support for research and the operation of the landgrant colleges.

administration. Through their agriculture experiment stations and their service bureaus, their activities were designed to serve the state.[74]

The impact of the Merrill Act on development of scientific and technical manpower is clearly evident in the case of the engineering profession. Before its passage, State legislatures had been reluctant to invest in technical education. Responding to the offer of Federal grants, however, they quickly sought to establish the new types of schools, while private colleges, caught up in the movement, also established departments of engineering.[75] Schools of engineering expanded rapidly, thereafter, numbering 110 by 1886. The number of engineering students similarly increased, from 1,000 in 1890 to 10,000 in 1900.[76] As more and more engineers were educated in formal institutions, there was a greater emphasis in engineering on science. Moreover, with the establishment and growth of these institutions, a profession was developed and with it a means of preserving, transmitting, and increasing an evolving body of engineering knowledge.[77]

The real impetus for manpower development, and for a strong Federal role in it, came, however, after World War II, when advanced technology had proven to be critical not only for the Nation's economic growth, but also for its defense. It was in recognition of this fact, for example, that the National Science Foundation was created in 1950 with the task of improving the Nation's potential in scientific research and in science education.[78]

The philosophical basis for establishing NSF, and the rationale for including the development of scientific manpower within its organizational mission, was explained by Vannevar Bush in *Science—the Endless Frontier*, *his* report to the President on a program for postwar scientific research. About the need for scientific manpower, he said,[79]

> . . . Today, it is truer than ever that basic research is the pacemaker of technological progress. In the 19th century, Yankee mechanical ingenuity, building largely on the basic discoveries of European scientists, could greatly advance the technical arts. Now the situation is different.
>
> A nation which depends on others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill.

Provoked by the successful launching of the Soviet spacecraft *Sputnik*, defense considerations also motivated the passage of the National Defense Education Act of 1958 (NDEA), which was aimed at improving instruction in mathematics, science, and foreign languages. Under this law, funds were provided on a matching basis to public schools, and as long-term loans to private institutions, for needed equipment in these instructional fields, for curriculum development, for guidance counseling, for vocational education in defense-related fields, and for teacher training in foreign language instruction. The passage of NDEA resulted in substantial increases in Federal aid to education (see fig. 29). Since Federal dollars had to be matched by State and local funds under provisions of the act, the overall investment in NDEA programs was large. Between 1958 and 1961, $163.2 million in Federal funds were dispersed. Approximately 75 percent of these funds were directed to the development of science curricula.

Although the U.S. educational system is organized on a local basis, the Federal Government has, over the years and in response to changing technological developments, come to influence the development of scientific and technical manpower in a number of ways. Particularly in the area of science and mathematics, the Federal Government has, for

[74]Clark Kerr, *The Uses of the University* (Cambridge, MA: Harvard University Press, 1972).
[75]Noble, op. cit., pp. 38-39.
[76]Edwin T. Layton, Jr., *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Cleveland, OH: The Press of Case Western Reserve University, 1971).
[77]Ibid.
[78]*The National Science Foundation and Pre-College Science Education: 1950-1975*, report prepared for the Subcommittee on Science and Technology, U.S. House of Representatives, 94th Cong., 2d sess., by the Congressional Research Service, Library of Congress, January 1976.

[79]Ibid., p. 19.

Figure 29.—A Quarter Century of Student Aid

25 years ago, the National Defense Education Act was signed

Student loans

NDEA, 1958

National Defense Student Loans, for which about $30 million was appropriated in the first year, were provided at an interest rate of 3 percent. The law told colleges to give "special consideration" to outstanding students who planned to become teachers in elementary and secondary schools and to those with a background of high achievement in science, mathematics, engineering, or a modern foreign language.

1983

The program, renamed National Direct Student Loans and transferred to the Higher Education Act, provided loans at an interest rate of 7 percent. About $193 million was appropriated for fiscal 1983. The debts are forgiven for borrowers who become teachers in schools serving disadvantaged students and those who teach the handicapped.

International education

NDEA, 1958

The law authorized support for fellowships, research, and university centers for foreign-language and area studies, putting emphasis on the training of specialists in languages "needed by the federal government or by business, industry, or education in the United States." Some $5 million was appropriated in the first year.

1983

The programs have been modified and incorporated in the Higher Education Act, with increased emphasis on supporting the education of nonspecialists as well as specialists in foreign language and area studies. About $26 million was spent on those programs in fiscal 1983.

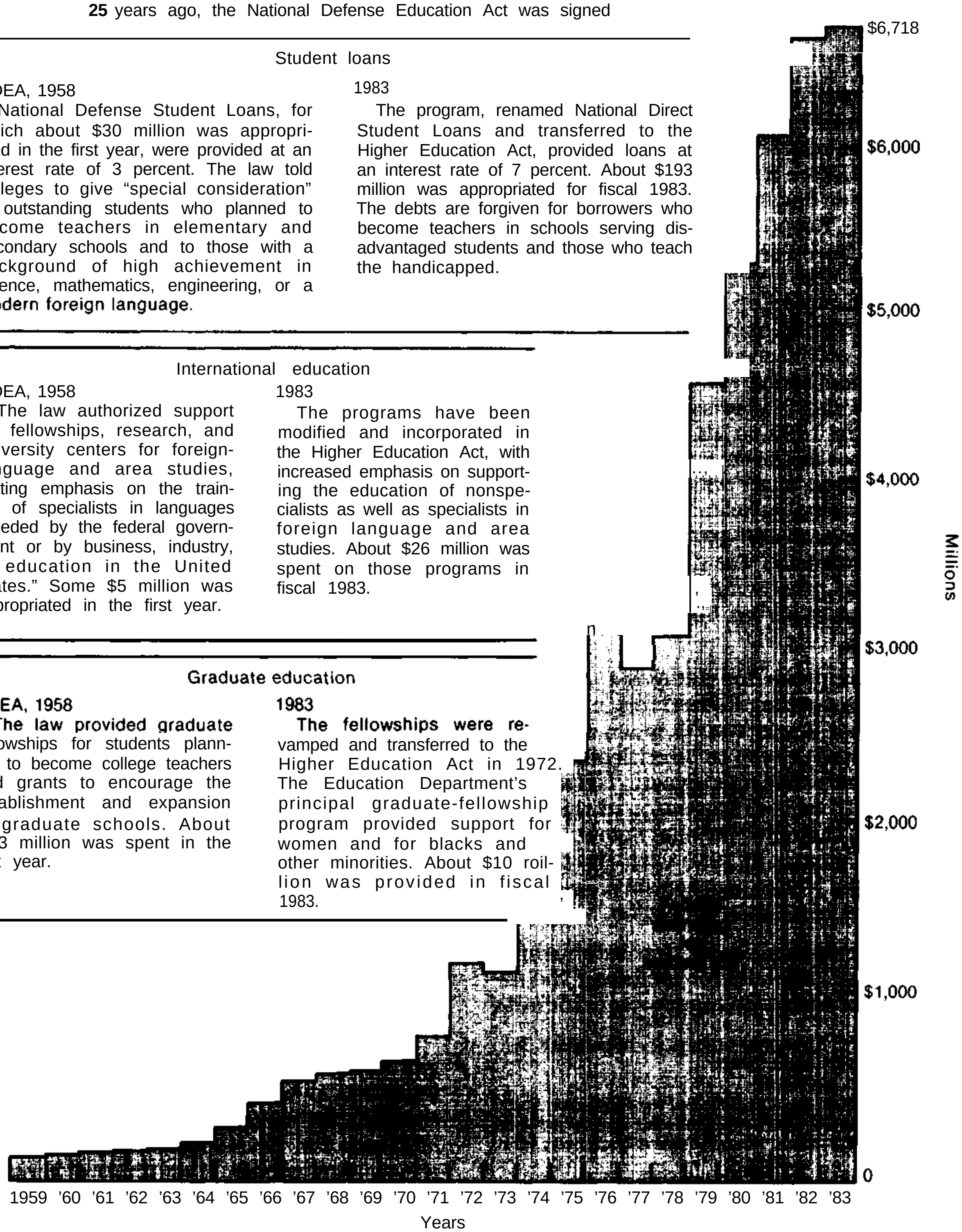
Graduate education

NDEA, 1958

The law provided graduate fellowships for students planning to become college teachers and grants to encourage the establishment and expansion of graduate schools. About $5.3 million was spent in the first year.

1983

The fellowships were revamped and transferred to the Higher Education Act in 1972. The Education Department's principal graduate-fellowship program provided support for women and for blacks and other minorities. About $10 roillion was provided in fiscal 1983.



SOURCE: Compiled by the American Council on Education, based on data from the U.S. Department of Education. Totals do not include Veterans Educa[lion Belnefits or Social Security Benefits for college students.

example, provided support for curriculum development and the production of new course materials. In addition, it has also lent considerable institutional support to colleges and universities, in the form of direct grants, research grants and contracts, equipment grants, and the establishment of institutes and specialized instrumentation centers. The Federal Government has, moreover, assisted individuals through training programs and fellowships as well as by providing scholarships and other forms of financial aid.

By targeting scholarships or fellowships for specific fields of study, the Government can also influence the direction of manpower development.[80] This was particularly true, for example, during the years following Sputnik when there was a widespread belief that the normal pool of technically trained graduates could not meet the manpower needs of the civilian space and the military ICBM programs. Where a large number of people have been involved, the Government has tended to provide only generalized incentives. Where the number is much smaller and the area of expertise quite specific, it has sought more to narrowly target its support.

"Ibid.

The Societal Context for Determining Federal Manpower Policy

The role of the Federal Government in development of scientific and technical manpower is not only indirect, it is also complicated. It is complicated by the fact that the Nation's educational system-the primary institutional means by which the Federal Government can affect manpower—serves a number of societal goals in addition to, and at times competing with, those that directly relate to manpower development.

Today, given the growing concerns about the United States' declining position in the international economy of high-technology goods and services, the American educational system is being called on to develop the Nation's scientific and technical manpower as a means of gaining for the United States a greater competitive edge. In examining this issue, this chapter has posed a number of questions about: 1) the causal relationships between education and economic performance, and 2) the extent to which there will actually be a critical shortage of manpower in the future to perform R&D in such high-technology areas as information technology. Before policy alternatives can be adopted to address the manpower problem, it is necessary to inquire further and to ask first whether or not Federal efforts to move the educational system more in the direction of manpower 'development can be achieved without sacrificing other equally, if not perhaps more important, educational and societal goals.

Education has always played a particularly important role in American society. For while educational institutions are publicly supported in many societies, in no other country have they been established with such deliberate purpose and public expectation, or been conceived of as being such an integral part of the political, social, and economic order. Contrasting the attitude of Americans towards education with that of Europeans, for example, Alexis de Tocqueville, the well-known French commentator on American society, noted in 1831:[81]

> Everyone I have met up to now, to whatever rank of society they belong, has seemed incapable of imagining that one could doubt the value of education. They never fail to smile when told that this view is not universally accepted in Europe. They agree in thinking that the diffusion of knowledge, useful for all peoples, is absolutely necessary for a peo-

[81] Alexis de Tocqueville, *Journey to America*, translated by George Lawrence, J.P. Mayer (cd.) Anchor Books, 1971.

> ple like their own, where there is not property qualification for voting or for standing for election. That seemed to be an idea taking root in every head.

The goals that Americans have sought to achieve through education have changed over time and in different historical circumstances.[82] In the earliest years of American history, for example, education was considered essential for the survival of the new democratic nation. Later, with the need to acculturate immigrants into society and to unite a divided Nation in the aftermath of the Civil War, it was considered the means for building a nation of citizens. At the turn of the century, education was expected to train and socialize American youths to participate in a modern, industrialized society. In the 1960s, Americans saw in education a way of providing equal access to social and economic opportunity.

Today, much of the national discussion about education has focused on the goal of meeting the manpower needs of a high-technology economy. Unlike earlier periods of American history, however, when the educational system was itself undergoing tremendous expansion and enjoying a period of considerable prosperity, today the educational system is having to take on a multitude of new tasks at a time when it faces the prospect of shrinking economic and human resources. Thus today, given limited social and economic resources for education, the choice to take Federal actions to increase the supply of manpower for R&D in the area of information technology might be made at the expense of addressing other educational problems or of meeting other educational and societal goals.

Some of the most important of the new tasks that educational institutions will have to perform are those that relate to the emergence of an "information society." In the recent OTA study, *Information Technology and Its Impact on American Education*, it was found, for example, that the growing use of information technology throughout society is creating new demands for education and training in the United States and is increasing the potential economic and social penalty for those who do not respond to those demands. Moreover, the study found that the information revolution is creating new stresses on many societal institutions, particularly those such as public schools and libraries that traditionally have borne the major responsibility for providing education and other information services.

New demands will also be placed on the educational system by virtue of the changes that are now taking place in the American economy. Programmable automation, for example, as the recent OTA study, *Computerized Manufacturing Automation: Employment, Education, and the Workplace*, points out, is one of the economic forces that is currently reshaping the roles for and the values being assigned to education, training, retraining, and related services such as career guidance and job counseling. This study concludes, moreover, that the inadequate capacities of the present instructional system may constrain the establishment of strategies to develop adequate skills for programmable automation.

Educational institutions will also be called onto perform a number of cultural tasks. Forecasts of demographic trends suggest, for example, that Hispanics, Asians, and other cultural groups with specialized educational needs will soon comprise a major portion of the school population. Moreover, the increase in the number of school-age children living with a single parent or two working parents will force schools to provide more supervision and socialization. In addition, a growing number of adults are turning to the educational system to fill in the nonvocational, liberal arts gaps in their educational backgrounds.[83] Thus, instead of cutting back on their educational activities, schools and universities will, most likely, have to cater to a growing number and variety of educational needs.

The role of the educational system as a means of providing equitable access to economic and social opportunities could become

[82] Welter, op. cit.; Cohen and Newfield, op. cit.; Tyack, op. cit.

[83] "More Adults Return to College to Study the Liberal Arts," Chronicle *of Higher Education,* Apr. 25, 1984, p. 1.

all the more important in an age of high technology. The Bureau of Labor Statistics, for example, has predicted that the number of low-skilled jobs will constitute an increasingly larger proportion of the total work force than the highly technical jobs.[84] Other social observers have suggested, moreover, that the wages earned by low-skilled workers will decline relative to those earned by technical workers.[85] Under such circumstances, the competition for educational credentials may become more intense in the future, and the issue of equitable access may become at least as important as, if not more important than, the issue of manpower development.

[84]BLS, Levin and Rumberger, **op. cit.**

[85]Bob **Kuttner, "The Declining Middle,"** *The Atlantic Monthly,* **July** 1983.

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