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The Supply of Information Technology Workers in the United States

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Executive Summary

The purpose of this study is to improve understanding of the supply of and demand for information technology (IT) workers in the United States, and the surrounding contextual issues. In conducting this study, the authors received support from the National Science Foundation, collaboration from five other professional societies, and guidance from the Computing Research Association Board of Directors.

There are four *major contributions* in this study:

1. Evaluation of data. The report identifies and evaluates all the major sources of statistical information relevant to this subject. The study group found that federal data are by far the most important and reliable, but that they have some serious shortcomings related to untimely reporting, occupational descriptions that are out of date and based on ambiguous job titles, and incompatibilities between supply and demand data collected by different agencies.

There are other data sources. However, it is questionable whether results drawn from geographically restricted and occupationally restricted data studies of IT workers can be generalized to the national IT labor force; and many of the national studies of IT workers done by private organizations have methodological weaknesses (see chapter 9).

2. Definition of 'IT Worker.' This report outlines a way of distinguishing IT workers from a much larger class of workers whose jobs are enabled by information technology. It then classifies IT workers into four categories (conceptualizers, developers, modifiers/extenders, and supporters/tenders) based not on their job titles, but on skills and knowledge required to do the job. An initial test of this categorization scheme in the State of Georgia has illustrated its value (see chapter 2).

3. Description of the Supply System. Some of the participants in the national debate identified bachelor's degree training in computer science as the principal supply source of IT workers. This report presents a detailed description of a much more extensive supply system, including not only majors in twenty different IT-related disciplines at the associate, bachelor's, master's, and doctoral levels, but also many people majoring in science, engineering, business, and even non-technical disciplines who often take some course work in IT subjects (see chapter 5).

The supply system also includes an increasingly important and rapidly growing continuing-education element. This continuing education is supplied not only by the traditional higher education system through short courses and certificate programs, but also by for-profit educators and by companies that are employing the IT workers. New modes of delivering instruction, such as asynchronous learning over the Internet, are rapidly being deployed (see chapter 6).

4. Analysis of shortage claims. The report evaluates the question of whether there is a shortage of IT workers in the United States. The study group determined that the data are inadequate to ascertain what mismatch there is, if any, between national supply and demand. Therefore the report makes use of a variety of other quantitative and qualitative kinds of evidence. These include: secondary indicators, such as wage growth and labor certificates awarded, based on federal data; quantitative studies restricted to specific geographical regions or specific IT occupations; private studies of the national IT labor market whose methodologies have come under question; anecdotal evidence about how employers have acted in their search to recruit or retain workers, or take alternative solutions such as refusing work or replacing workers by machines; and other kinds of qualitative evidence.

The preponderance of evidence suggests that there is a shortage of IT workers, or at least a tight labor market. None of this evidence has the certainty of a direct count of supply and demand, and without this kind of direct count it is impossible to distinguish an actual shortage from a mere tightness in the labor market. Moreover, there are credible reasons for questioning the evidentiary value of virtually any piece of evidence that is available (see chapter 4).

One of the problems with the national debate is that IT workers have been treated as a single, undifferentiated group. However, the phrase 'information technology worker' encompasses many different occupations that require a wide array of skills and knowledge. It would be helpful in future discussions to segment the class of IT workers into classes of occupations that have similar levels of knowledge and skill. It would be surprising, given the dynamism and demand in the IT labor market, if there were not some spot shortages (and some spot surpluses). Unfortunately, existing data do not allow this kind of segmented analysis.

Of the many *contextual issues* that need to be considered to gain a full understanding of the supply and demand of IT workers, this report examines four:

5. Political context. The study group evaluated the reports by the Information Technology Association of America (ITAA) and the Department of Commerce, as well as the criticism of these reports by the U.S. General Accounting Office

(GAO). We agree with GAO that the low response rates in the surveys of industrial demand are a serious weakness in the ITAA and Commerce reports; but this speaks against the quality of the evidence, not necessarily against the conclusion that there is a shortage. The ITAA and Commerce reports can also be faulted for their narrow focus on recipients of computer science bachelor's degrees when discussing the supply of IT workers (see chapter 1).

The legislation providing a temporary increase in the number of temporary visas permitted annually under the H-1B visa program was also reviewed. CRA and the other professional societies participating in this study did not take a position on the H-1B increase when it was being debated in 1998, and it is not our intention to second-guess the program now. We believe that the legislation probably will increase the total supply of workers during a period of episodic higher demand created by the Y2K problem, while limiting the risk to the indigenous supply system through a sunset clause on the increase in visas awarded (see chapter 1).

6. *Types of demand.* This report differentiates two kinds of demand. There is *episodic demand*, such as this country is experiencing currently as it struggles with the Y2K problem and the sudden spurt in Internet activities. There is also a *long-term demand*, created by fundamental changes in technology and society. The long-term demand for IT workers is driven by the relentless decrease in the size of information technology, as well as its relentless increase in performance, reliability, flexibility, and price-for-performance. Because of these changes, information technology is rapidly being adopted by every sector of American society and made a fundamental part of organizational operations and personal activity. Perhaps the greatest weakness in the H-1B legislation is that it focuses on a short-term problem created by an episodic demand. It does not address the long-term problem of providing an adequate supply to meet the demand for IT workers that is likely to continue to grow unabated well into the new millennium (see chapter 3).

7. *Limitations on action.* Even when organizations recognize a mismatch between supply and demand that they would like to overcome, there are almost always limitations on their ability to act. A government organization cannot regulate supply and demand; it can only provide incentives, such as fellowships, to encourage students to choose an area of expertise that appears to be in short supply. But it is difficult for a government to stimulate labor supply by just the right amount since the market is constantly changing, knowledge about supply and demand is imperfect and difficult to obtain in a timely fashion, and there are often unforeseen consequences of any government action.

Industry has its own constraints. For example, companies are forced by short product life and short product development cycles to hire new employees or reassign existing workers in ways that do not require a lot of break-in training before they can be productive.

The traditional higher education system is constrained by its inability to change directions quickly. This results from its limited resources to allocate to new or growing disciplines, the long-term commitment colleges and universities make in buildings and capital equipment or in tenured faculty appointments, and its deliberative style of decision-making (see chapter 3).

8. *International considerations.* There is a rising international demand for information technology. Companies throughout the world are taking advantage of the changes in information technology that allow them to use it to improve their operations. There is increasing global competition to supply IT products and services. International and foreign firms are thus competing with U.S. firms for the skilled workforce to develop IT products and services and place them into operation. Only a few countries (e.g., India and Ireland) have a surplus of IT workers; and there is strong competition from many countries, including their home countries, for these workers. The United States will have to assure an adequate supply of IT workers if it wants either to retain its world lead in the IT sector, or remain competitive in other industry sectors that rely on information technology. Foreign workers can play an important role in the United States, but they are unlikely to help meet our growing demand for IT workers in this manner (see chapter 3).

Other topics. This study could only touch on a number of other topics that are important to adequately understand IT workforce issues. A number of groups are underrepresented in the IT workforce and in the educational programs that prepare people for careers as IT workers. These include women, Hispanics, African Americans, and Native Americans. If these groups were represented in the IT workforce in proportion to their representation in the U.S. population, this country would have more than an adequate supply of workers to fill even the most dire estimates of a shortage. Because other studies have investigated the underrepresentation of women or minorities in professional work, scientific and engineering fields, including the computing profession, this study chose to focus its efforts on other issues that have been less thoroughly investigated. However, some basic information and statistics about the issues concerning the participation of women and minorities in the IT field have been collected here. Some of the issues concerning women mentioned here are the lack of adequate exposure to computers during the K-12 years, the scarcity of role models, and perceptions about what it is like to be an IT worker (e.g., competitive work environment, focus on machines rather than people, and so on). This study found many of the issues for minorities to be similar to those for women; but there is the added problem that minorities are not as likely as white males or women to attend college or graduate school. It is clear that these issues of underrepresentation need more attention than they could be given in this study (see chapter 7).

It may also be true that older workers are underrepresented in the IT workforce. There is certainly a widespread perception that programming is an activity for the young, and that IT workers tend to get "burned out" and leave the field by the age of 40. The absence of almost any data precluded this from being a major topic of study in this report. The study group looks forward to the examination of this important issue in a forthcoming study by the National Research Council (see chapter 7).

Some people are concerned about a seed-corn problem: that the high industrial demand for IT workers is siphoning off too many graduate students and faculty from the universities, leaving an insufficient number to educate the next generation of IT workers. This study detected preliminary signs of a seed-corn problem. The coordinated efforts by government, industry, and academia to solve a seed-corn problem in computer science that occurred around 1980 are recounted. Some of the problems today are the same as in 1980, such as the rapid increase in undergraduate enrollments placing heavy loads on faculty. However there are also some differences: universities today have better research equipment, compared with that in industry; than they did then; however, research support now emphasizes short-term research too much, and it is harder for industry to coordinate voluntary restraint on faculty and student raiding today because the industrial employers of research computer scientists are today much more widely spread across many different industries (see chapter 8).

The authors struggled with the decision whether to include *recommendations* in the report. The mandate for this study was to provide an understanding of the issues surrounding the supply of and demand for IT workers, not to provide a call for action. In most policy reports, the recommendations have primacy and the analysis is included merely in a supporting capacity. The study group did not want the presence of recommendations to undermine the attention paid to the analysis. Also, as a study group, we do not have any particular standing within the government, industrial, or academic sectors from which to recommend actions.

On the other hand, a number of important issues were raised and actions suggested by the study group during the course of the study. Given the wide range of knowledge and experience represented by the study group, we decided it would be useful to put these suggestions forward in the hope that they will stimulate further discussion and action. Mostly, the recommendations identify a problem and a general course of action without trying to be specific about implementation mechanisms.

The thirty-seven recommendations are grouped around a small number of issues: data-collection practices, industry-academic cooperation, industry hiring and training practices, certification of educational and training programs, broadening the supply pipeline, improving the research and teaching environment to retain and recruit faculty, and curriculum development. The recommendations are organized according to intended audience: government, higher education, industry, professional societies, and individuals (a summary of the recommendations can be found at the end of chapter 10 as box 10-1).

Chapter 1. Political Context

What Is This Report's Evaluation of Earlier Studies?

Human resource issues related to information technology have frequently been on the national agenda since the early 1960s, when the National Academy of Sciences (NAS) and the National Science Foundation (NSF) began preparing studies and collecting data on this subject. These efforts supplemented data that have long been collected by the Bureau of Labor Statistics (BLS).

The most recent national debate began in 1997 with a report prepared by the Information Technology Association of America (ITAA), a trade association representing 11,000 companies. ITAA reported a large shortage of IT workers in large and mid-size U.S. companies. In 1998, ITAA published a second report based on a larger sample of companies, which indicated an even more serious shortage of workers. The Department of Commerce's Office of Technology Policy then issued a report that largely mirrored the conclusions in the original ITAA report. The General Accounting Office (GAO) criticized the methodology used to gather the data put forward by both ITAA and Commerce, and questioned their conclusions about a shortage. Individuals and private organizations weighed in on the debate, which quickly crystallized around proposed legislation to increase the number of temporary H-1B visas that could be awarded annually. Compromise legislation was passed by Congress in October 1998 and subsequently signed into law.

However, it is clear that this legislation does not end the national discussion of IT workers. The legislation is temporary, lasting only three years, and it addresses only one aspect of this complex labor issue. Questions about the treatment of older IT workers, for example, were largely ignored in the H-1B debate. The importance of IT workers to national competitiveness and national wealth, and the dynamic nature of information technology, which is rapidly being incorporated into every sector of the U.S. economy, strongly suggest that issues surrounding the IT workforce will be part of national policy discussions for years to come.

Although this report primarily addresses current and future issues about IT workers, this chapter is devoted to an examination of some aspects of the political context concerning IT workforce issues in the United States. This analysis begins with a review of some of the arguments presented in the ITAA and Commerce reports.

The discussion will focus primarily on vacancy rates, which are used as a principal kind of evidence in the two ITAA studies.[1] The first study, undertaken by the Cato Institute, a libertarian think-tank, involved telephone interviews with randomly chosen companies (in various sectors, not just IT companies) that employed 500 or more workers (counting all their workers, not just IT workers). Only 271 of 2,000 companies responded, giving a response rate of 14 percent. The second study, undertaken by the Continuing Education Division of Virginia Tech, was also a telephone survey, but this time the targets were companies with 100 or more employees. From a sample size of 1,500 companies, 532 interviews were completed, giving a somewhat better but still low response rate of 36 percent. The first study argued that 190,000 IT jobs were unfilled in the United States in 1996. The second study claimed 346,000 IT vacancies—representing a 10-percent vacancy rate.

GAO argued that the low response rates and small sample sizes made the results of these surveys highly questionable.[2] It is true that the results might be skewed because companies that were experiencing more serious shortages may have been more likely to respond. However, there is no hard evidence from any statistically valid study that refutes either the ITAA results or the presence of an IT worker shortage. While the ITAA results may not have the weight of scientific evidence, they do suggest that many U.S. companies are having difficulties filling their IT positions. This evidence is consonant with many other anecdotal reports heard while researching this study.

This finding is bolstered by a GAO observation that the unemployment rate for IT workers was only 1.3 percent in 1997, which is

[1] "Help Wanted: The IT Workforce Gap at the Dawn of a New Century," Information Technology Association of America, Arlington, VA, 1997; "Help Wanted 1998: A Call for Collaborative Action for the New Millennium," Information Technology Association of America and Virginia Polytechnic Institute and State University, March 1998. For a more detailed critique of the first ITAA report, see Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998. It persuasively argues that there are methodological problems with one after another of the kinds of evidence of shortage given in the ITAA report.

[2] See, for example, U.S. General Accounting Office, "Information Technology: Assessment of the Department of Commerce's Report on Workforce Demand and Supply," GAO/HEHS-98-106, March 1998; GAO, "Information Technology Workers: Employment and Starting Salaries," GAO/HEHS-98-159R, May 1998.

much lower than the 4 percent often considered by economists to represent "full employment." In fact, even when the IT unemployment rate hit its historical high for recent times—3 percent in 1991—it was below the 4 percent threshold indicating full employment. This is perhaps to be expected, given that most professional occupations that are filled primarily by highly educated workers have low unemployment rates.[3] Since 1987 the IT unemployment rates have tracked up and down in parallel with the national general unemployment rate, although the IT rates are consistently lower by a factor of 2 to 3. Given that the general unemployment rate is currently at a 25-year low, it is not at all surprising that the IT labor market is experiencing some tightness.

The Department of Commerce report,[4] like the first ITAA report, compares the projected number of IT jobs to the supply as an indicator of a shortage. For demand, Commerce used a Bureau of Labor Statistics (BLS) projection that between 1994 and 2005 the number of IT jobs in the United States would increase annually by 95,000. Commerce contrasted the projected annual increase in demand with data from the National Center for Education Statistics (NCES). The NCES data indicated that only 25,000 bachelor's degrees in computer science are produced annually in the United States—and that these numbers have been steadily decreasing from a high of 42,000 in 1986 (a 40-percent decline).

GAO rightly criticized Commerce's argument—by noting that there are additional kinds of formal computing training besides bachelor's degrees, such as associate degrees and certificate programs, that prepare people for IT careers; and also that most IT workers receive their formal education in fields other than computer science. In consonance with GAO's line of reasoning, this study group believes that to understand whether there is an IT worker shortage, one must consider both the multiple sources of supply and the various occupations for which each of these sources prepares an IT worker. There are many IT jobs, such as help desk attendant or Web designer, for which an undergraduate computer science degree is neither common nor appropriate training.[5] Another problem with the ITAA

[3] According to a data brief from R. Keith Wilkinson, Science and Resource Studies, NSF, the unemployment rate for science and engineering degree-holders was less than half the overall national average: 2.2 percent for those working in science and engineering, and 2.8 percent for science and engineering degree-holders in other than science and engineering occupations, versus 5.6 percent for the U.S. labor force as a whole in 1995. See http://www.nsf.gov/sbe/srs/databrf/sdb/98325.htm for details.

[4] U.S. Department of Commerce, Office of Technology Policy, "America's New Deficit: The Shortage of Information Technology Workers," Fall 1997.

[5] Brian Hawkins, the president of EDUCAUSE, has noted that there are reasons why IT jobs that do not require a computer science degree are advertised with this degree requirement: "Often HR personnel do not fully understand such issues all that well, when job specifications and job descriptions are written. Sometimes this is done in an attempt to artificially elevate the position deliberately, in an effort to get the position graded at a level that the salary could attract reasonable candidates, who may or may not have such qualifications." Personal communication, March 8, 1999.

line of reasoning is that the decline in the production of bachelor's degrees in IT-related fields has ended. There was a very significant national upswing in the number of students entering bachelor's degree programs in computer science in 1997 and 1998. The CRA Taulbee Survey of Ph.D.-Granting Departments of Computer Science and Engineering indicates that new declarations of majors in computer science at the bachelor's level have doubled over these two years, and much higher graduation numbers can be expected as these students complete their undergraduate degrees. Enrollments still are not as high as they were at their peak a decade earlier, however.

As another indicator of a shortage, the Commerce report cited the fact that some U.S. companies were outsourcing work to other countries. GAO correctly observed that the statistical data to support this claim are not compelling. The Commerce report discussed the size of the IT workforce in other countries, such as India, and mentioned percentages of that country's IT work being done for export. However, it was difficult to apply these statistics meaningfully as an indicator of a worker shortage in the United States. It would have been useful to have statistics about the percentage of IT work for U.S. companies being outsourced overseas and how that percentage has changed over time. The significance of even these statistics, however, would not be unambiguously clear. Outsourcing is a tried-and-true method used by companies for financial and other reasons, and the presence of outsourcing does not, in itself, represent evidence of a worker shortage. Outsourcing outside of the United States may be an indicator of limited U.S. capacity to do this work, but it is hard to tell without further examination. For example, the lower cost of having programming done overseas or the desire of a company to establish a presence in a particular country might be reasons for foreign outsourcing that have nothing to do with a shortage of American workers.

The final argument given by Commerce as evidence of a worker shortage is the increase in salaries of IT workers. The report cites three private studies of IT worker compensation that show annual salary increases in 1996 and 1997 averaging between 7.4 percent and 20 percent—much higher than the overall average increase in compensation for U.S. workers (4.1 percent). GAO gives two counter-arguments. The first is that this may be evidence of a tightening labor market rather than an actual shortage of workers. On this point, GAO's argument may be focused too much on the near term. Regardless of whether there is a 'shortage' or merely a 'tightness' today, if the demand for IT workers continues to grow rapidly in the next decade—as the BLS itself predicts and our study group expects—any tightness would soon become a shortage, unless supply can find a way to keep up with demand.[6]

[6] BLS has projected that between 1996 and 2006 the IT-related occupations (i.e., computer systems analysts, engineers, and scientists) will grow by 107.6 percent, compared with an overall job growth of only 14 percent in the United States. BLS, *Monthly Labor Review*, November 1997.

GAO's second criticism was the use of BLS data to argue that IT occupations have, at best, merely kept pace with average salary increases in the professional and specialty occupations overall from 1983 to 1997 (although IT workers started from a considerably higher base salary). One problem with this argument is that BLS data are strongly at odds with private data, such as employer compensation surveys. One reason may be that the private studies take bonuses and stock options into consideration, whereas BLS considers only base salary. There is anecdotal evidence that spot shortages have driven up salaries. Two or three years ago, for example, new graduates with a bachelor's degree in computer science were being offered starting salaries up to double the average of their peers if they were experienced in building local area networks—a new skill that was then in short supply. Some schools are reporting a similar increase today in salary offers for students graduating with experience in information security.

Most people interested in this labor issue have focused on the differences between the positions taken by Commerce and GAO, but there are, in fact, many areas of agreement. GAO has publicly stated, for example, that it agrees with the Commerce report on past and expected growth in demand for IT workers, current low unemployment rates for IT workers, and the need for a better understanding of supply-demand dynamics and better categories and data in order to develop good policy.

How Does Recent Legislation on H-1B Visas Affect Any Shortage?

This study group did not take a position for or against the legislation that temporarily increased the number of H-1B visas that may be awarded annually.[7] Nevertheless, a number of points can be made about the likely effects of this legislation on the IT workforce.[8]

- Given that there is a sunset clause in the legislation that increases the cap, this legislation will clearly not be a long-term factor unless it is renewed.

- The number of IT workers entering the United States under the H-1B program is and will continue to be a small percentage of the total IT workforce in this country. According to BLS, there are approximately two million IT workers in the United States. The limit on the number of workers of all types entering this country on H-1B visas was 65,000 per year. This limit will increase to 115,000 for 1999 and 2000, before dropping back to the

[7] For a discussion of the legislation that increased the annual cap on H-1B visas, plus a labor perspective on the legislation, see Greg Gillespie, "Congress Expands H-1B Visa Program," IEEE, *The Institute*, December 1998, p. 1.

[8] For another view on H-1B, Y2K, and the larger, long-term issues of IT workers, see Howard Rubin, "The United States IT Workforce Shortage," *Dr. Dobb's Journal*, Fall 1998, on the Dr. Dobb's Web site at http://www.ddj.com/articles/1998/9814/9814b/9814b.htm

65,000 level. H-1B workers enter a number of occupations, such as baker and fashion model; not all of them are IT workers. The best estimate from unreliable data is that from 20,000 to 25,000 of these 65,000 visas have been going to IT workers, and it is difficult to predict how many will go to IT workers in the future. Since the visas are temporary, the workers can stay in the country on this visa for only six years. In fact, a number leave before their visas expire. For these reasons, H-1B workers are likely to represent a small portion (perhaps less than five percent) of the national IT workforce.

◆ Of H-1B workers who do IT work, there is no good evidence about where they are likely to be employed or what effect they will have on the domestic IT labor pool. The specific kinds of IT work they will do is unknown. The top ten users of these visas in the past have been companies providing contract labor and services. By far the largest user has been the Mastech Systems Corp. in Pittsburgh, which has received visas for 1,733 of its employees—80 percent of its workforce. These workers are virtually all programmers who hold a bachelor's degree as their highest level of education. However, there is also some demand for H1-B workers in more highly skilled, higher paying positions. They include research scientists in industrial research laboratories or faculty members in research universities, where they serve the nation by creating new technologies that generate national wealth and by training the next generation of IT workers. For example, Intel Corp. says that, of its 67,000 employees, about 3 percent have been hired using H-1B visas, and nearly 80 percent of these hold a master's or doctoral degree. There is no way to determine whether the larger number of temporary workers entering the United States under the expanded program will continue to be employed by companies like Mastech or by companies like Intel.

◆ The cost of the visa, which approaches $15,000 when legal fees are included, limits the extent to which H-1B visas will be used to fill lower-skill positions.

◆ The attention paid to the H-1B visa has obscured the existence of another major source of skilled foreign labor, including IT workers. The TN visa (commonly known as the 'NAFTA visa') permits unlimited numbers of Canadian IT professionals to enter the United States for work, and it will offer similar opportunities to Mexicans beginning in the year 2003. There is some evidence that a brain drain of IT workers from Canada is hurting the Canadian IT industry.[9]

◆ Making the increase in the number of visas awarded under the H-1B program a temporary measure is well justified. It is very difficult to accurately forecast national shortages. Witness the NSF

[9] On the IT worker situation in Canada, see the Software Human Resource Council's report, "Taking Action on Canada's IT Skills Shortage" (http://www.shrc.ca/Taking%20Action/front_page.htm); SHRC's Occupation Skills Profiles Model (the Canadian Advanced Technology Association's call to "double the pipeline" (http://www.cata.ca/cata/advocacy/skillshortage.htm); and the British Columbia Technology Industries Association report, "Technology Industries in BC: A 1997 Report Card" (http://www.bctia.org/industry/report/).

forecast in 1990 of a “shortfall” of scientists and engineers in general, which did not materialize; in fact, many people now believe there is an oversupply. Generally speaking, legislation has never been a very effective tool for balancing supply and demand in any occupation. It is possible to harm the indigenous supply system by bringing in too many foreign workers. It is also possible that foreign workers are filling positions that might otherwise have been filled by American citizens, such as older electrical engineers who have lost their jobs in the downsizing of the defense industry, although the study group uncovered no hard evidence of this. A limited-term increase in the temporary visa program will provide an opportunity to study some of these issues before any additional immigration legislation is considered.

◆ The current legislation may serve well to ameliorate the current, but episodic, demand for IT workers caused by the Y2K problem by covering some of the total demand for IT workers (but not necessarily by doing Y2K work itself). For reasons that are explained elsewhere in this report, the demand for IT workers will probably continue to grow steadily and rapidly over the coming decades. In fact, because information technology affects so many sectors of American industry, the growth in demand for IT workers is likely to continue unabated, even in times of general economic malaise or when IT companies themselves have a downturn. Thus, in the long term, the country will have a large capacity to absorb new workers from both domestic and foreign sources. Y2K is a special and important problem, but it is temporary. It represents a sharp, short-term peak on the long upward curve of continuing, long-term demand for IT workers. There will be other short-term peaks as well, such as the end-time date for Unix systems early in the next century. While eventually there will be a sufficient growth in demand for IT workers that the U.S. economy could possibly absorb all of the foreign workers hired to fix Y2K problems, it is unclear whether there will be some temporary displacement of IT workers after this short-term crisis is over. To lessen the risk of displacement of American workers, it appears to be sound policy to fill some of this short-term spike in demand for the Y2K problem with temporary foreign workers.

To complete this discussion of the H-1B issue, it is useful to compare this visa program with legislation in 1989 dealing with labor shortages of nurses reported by some hospitals and other employer groups. The history of this legislation and its effects on the shortage of nurses is an illustrative case study for understanding the IT worker shortage. In fact, this H-1A visa legislation for nurses provided the structure for the legislation in 1990 that created the H-1B visa program. The case study is recounted in box 1-1.

Box 1-1. H-1A Visas and the Nursing Shortage

In response to labor shortages of nurses reported by hospitals and some other employer groups, the Congress passed the Immigration Nursing Relief Act of 1989 (INRA, Public Law 101-238). This law added a new provision allowing admission of nonimmigrant registered nurses (RNs) during a five-year pilot period to expire in September 1995.

The history of this program was carefully reviewed in 1995 by the Immigration Nursing Relief Advisory Committee established under the above law, and its report provides an instructive model for discussion of the issues surrounding the debate about foreign IT workers. The rationales for the H-1A nursing visas were:

a) reports of a nationwide shortage of nurses;
b) increasing dependence on foreign temporary nurses admitted under other visas;
c) pending expiration of work authorizations for many existing temporary foreign nurses admitted under other programs;
d) concern that foreign nurses were detrimentally affecting the pay and working conditions of the domestic nursing workforce; and
e) declining numbers and quality of applicants to basic nursing education programs.

The new act, first, allowed foreign nurses previously admitted on temporary visas to convert their status to legal permanent resident, and waived numerical limits in existing law in order to allow this to happen. Second, it created a new temporary nursing visa (the H-1A visa) that included provisions intended to: 1) encourage employers to reduce their dependency on foreign nurses, 2) provide protection for the wages and working conditions of nurses who are citizens and legal permanent residents of the United States, and 3) foster the development of a stable pool of domestic RNs so that future shortages could be minimized.

According to the Advisory Committee, the debate on this particular legislation embodied many of the issues that repeatedly arise in discussions regarding the admission of foreign workers to meet skill shortfalls and labor shortages in the United States. The Advisory Committee summarized these issues with a long quotation from a 1991 staff report:[10]

The debate about relying on immigration more significantly to meet "labor shortages," and thereby contribute to America's competitiveness in the global marketplace, inevitably included the need to provide realistic protection for U.S. workers. For immigration policy, this issue involved two interrelated points. First, how to evaluate independently an employer's claim that a foreign worker is needed. And second, how to strike an

[10] Gary B. Read and Demetrios G. Papademetriou, "U.S. Legal Immigration Reform: Recent Developments," Immigration Nursing Relief Advisory Committee report, 1995, pp. 12-13.

intellectually and politically satisfactory balance between being responsive to employer needs while also being sensitive to concerns that greater access to foreign workers by U.S. employers might affect adversely the wages and job opportunities of U.S. workers. Such adverse effects could occur through direct displacement of U.S. workers or through significant interference with the market's natural propensity to adjust to a tighter labor supply, thereby leading to an increasing dependence on foreign workers. This debate clearly raised the issue that over-reliance on immigration to meet labor shortages, as opposed to educating and training the domestic workforce, could turn temporary labor market shortages into structural deficiencies.

The conclusions of the Advisory Committee were mixed. They noted that because only a tiny percentage of the U.S. nursing workforce ever came to be accounted for by H-1A nurses (about 13,800 in 1994, less than 1% of employed RNs), at the national level essentially all the effects of this program were negligible. However, because the H-1A nurses were heavily concentrated in only a few metropolitan areas (over one-third in the New York City area alone, and two-thirds in New York, Chicago, Houston, Los Angeles, and Dallas together), H-1As in these cities mitigated a tight nursing labor market with "no adverse impacts on patient care," but also "may have lessened the pressure to find long-term solutions to nurse staffing problems." [11]

The Committee found the "attestation" procedures required of employers to be ineffectual, and reported that the "use of employer-specific vacancy rates as a justification for the need for H-1A nurses was problematic, as these rates could be calculated in several ways, making them difficult to verify." It noted further that the prevailing wage determinations were often of doubtful validity and reliability, and that the act's requirement that "employers take timely and significant steps to recruit and retain U.S. nurses was ineffective because it did not require any new steps" beyond those that most employers had long practiced. [12]

Lastly, the Advisory Committee reported that the rate of increases in RN employment had slowed since passage of the 1989 Act; that press reports had begun to appear about nurse layoffs; and that "the future labor market for registered nurses is uncertain."[13] The H-1A nursing visa program was allowed to expire in September 1995. In its final year, FY1994, approximately 6,300 nonimmigrant nurses had been admitted under this visa program.

Source: Computing Research Association, Intersociety Study Group on Information Technology workers, based on the "U.S. Legal Immigration Reform: Recent Developments," Immigration Nursing Relief Advisory Committee report, 1995.

[11] Ibid., p. 5.

[12] Ibid., p. 6.

[13] Ibid., pp. 7, 31.

Chapter 2. Information Technology Workers

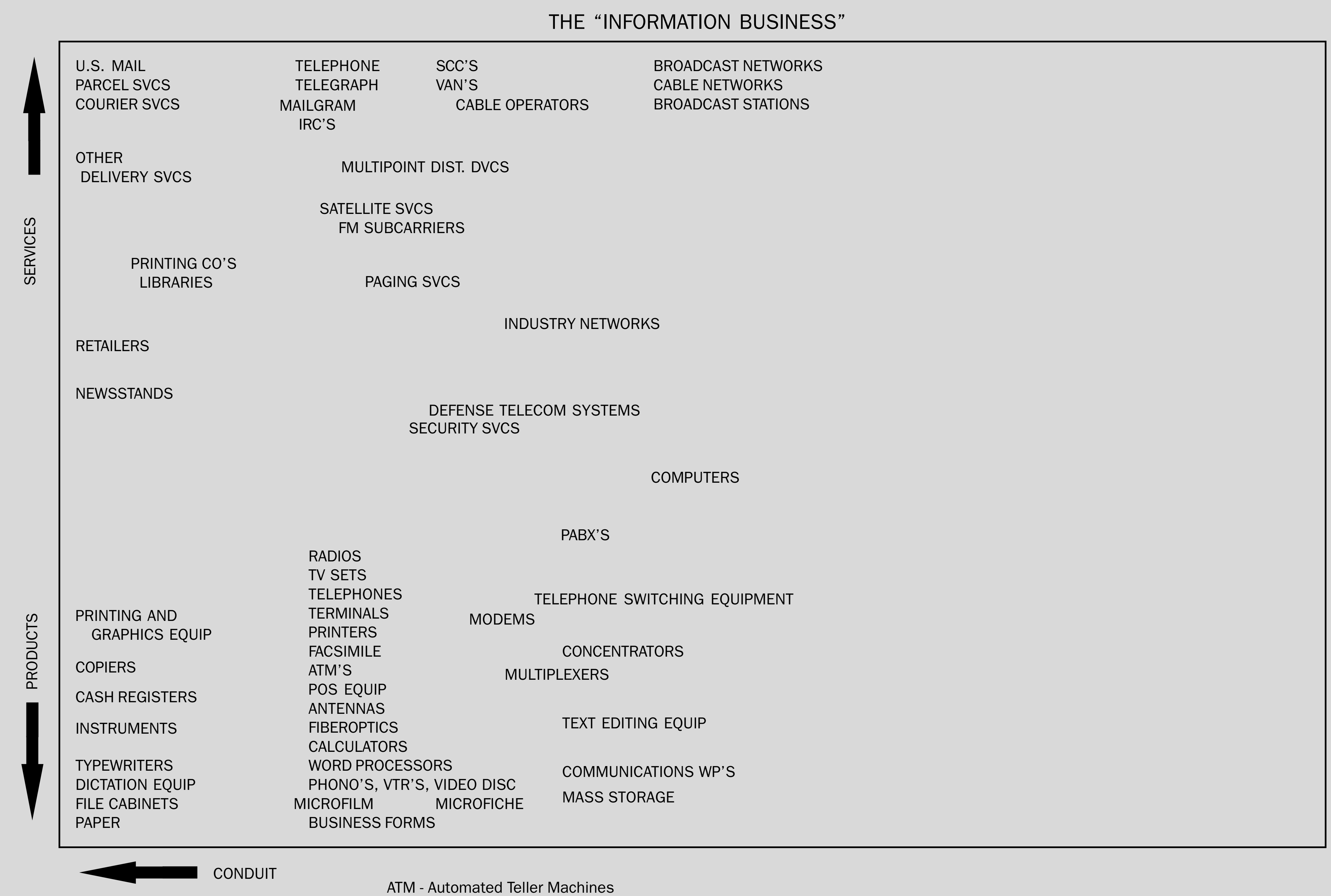
What Is Information Technology?

This report uses the terms 'information technology' and 'information technology worker' because they are used in the national discussions about these labor issues. Unfortunately, these terms are somewhat imprecise and are used in different ways at different times. Figure 2-1, taken from a dated but still useful study by John McLaughlin and Anne Birinyi, gives a broad definition of the 'information business.' From this figure, one could infer a broad definition of information technologies that would include, among many others, computers, telephones, radios, televisions, books, and filing cabinets. This report does not use such a broad definition.

In this discussion, information technology (IT) refers only to computer-based systems. It includes computer hardware and software, as well as the peripheral devices most closely associated with computer-based systems. We define 'computer-based systems' broadly to include the full gamut of technological considerations, ranging from the design and production of chips (for example, Intel is widely regarded as an IT company); through the design and creation of complex, computer-based systems for a particular application (the modernization of the U.S. Internal Revenue Service tax-processing system was certainly considered to be an IT problem); to the end-use of such systems (most of the electronic commerce startup companies are considered to be part of the 'IT revolution,' at least for the purpose of tracking and reporting).

There is a certain amount of ambiguity to this definition. To clarify, it may be helpful to compare it with some other commonly used terminology and concepts. The term 'information system' is sometimes used to refer to computer-based systems that provide information for decisionmaking in organizations, which results in the use of 'information technology' and 'information systems' in closely related ways. This usage (e.g., "He heads up the corporation's IT operations") focuses on the *purpose*

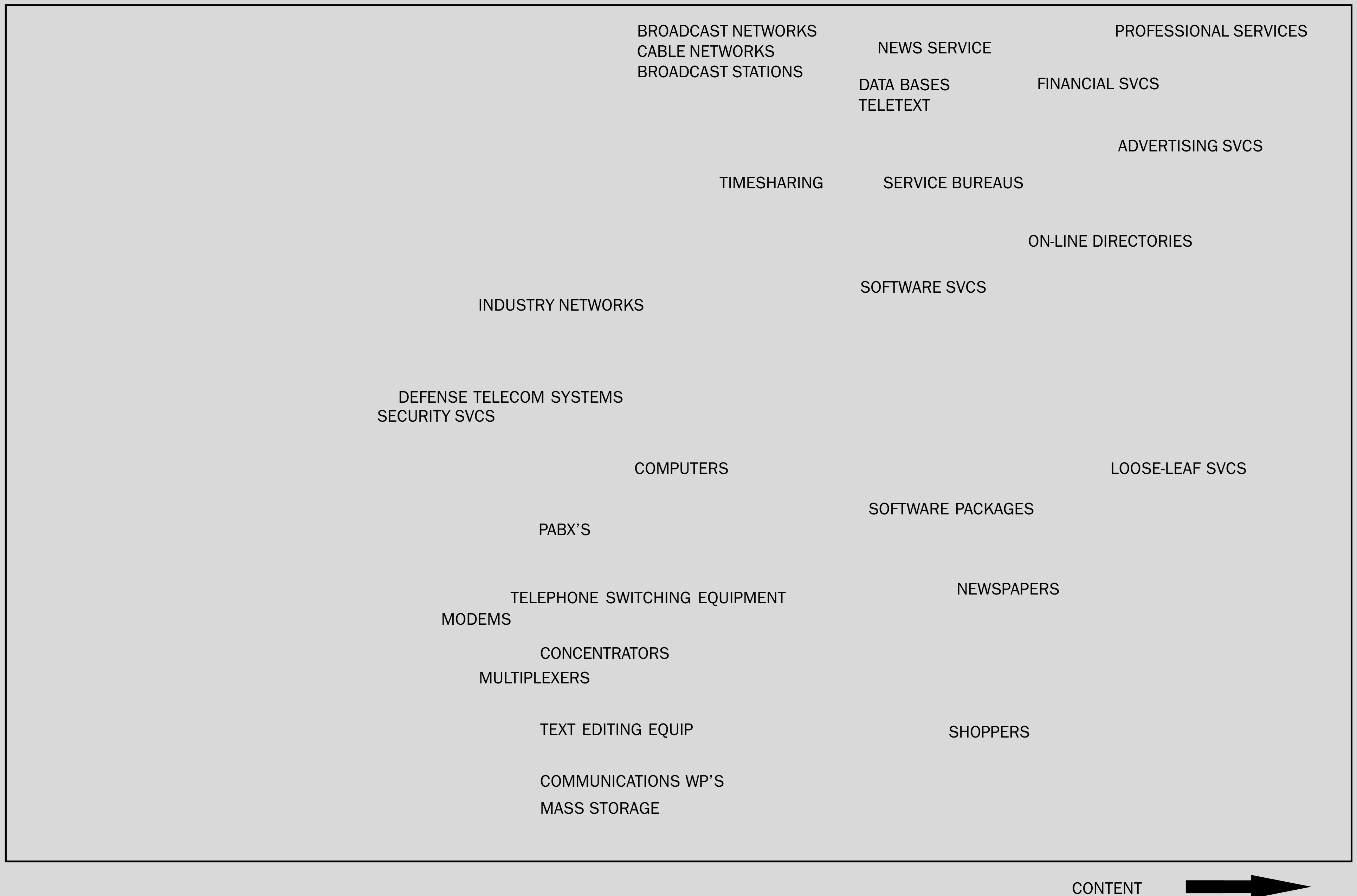
Figure 2-1



ATM - Automated Teller Machines
IRC - International Record Carrier
PABX - Private Automatic Branch Exchange
POS - Point-of-Sale

Source: John McLaughlin and Anne Birinyi, "Information Business," Harvard College, 1980.

THE "INFORMATION BUSINESS"



ATM - Automated Teller Machines
IRC - International Record Carrier
PABX - Private Automatic Branch Exchange
POS - Point-of-Sale
SCC - Specializied Common Carrier
VAN - Value Added Network
VTR - Video Tape Recorder
WP - Word Processor

Source: John McLaughlin and Anne Birinyi, "Information Business," Harvard College, 1980.

Table 2-1

IT-related Academic Disciplines Offered in the United States

1. Computer Science	11. Performance Analysis (Capacity Planning)
2. Information Science	12. Scientific Computing
3. Information Systems	13. Computational Science
4. Management Information Systems	14. Artificial Intelligence
5. Software Architecture	15. Graphics
6. Software Engineering	16. HCI (Human Computer Interface)
7. Network Engineering	17. Web Service Design
8. Knowledge Engineering	18. Multimedia Design
9. Database Engineering	19. System Administration
10. System Security and Privacy	20. Digital Library Science

Source: Peter Denning, "Information Technology: Developing the Profession," Discussion Document, December 4, 1998.

of the system rather than its underlying technology. In this report, the underlying technology of an information system (as used in the example above) is considered to be an example of information technology. The definition of information technology, however, is not restricted to any particular application area. Indeed, one of the attributes of information technology that makes it worthy of study is its pervasiveness in society.

There may be as many as twenty academic specialties that study various aspects of information technology and its use and applications (see table 2-1). Box 2-1 and the accompanying text in chapter 5 lists and reviews definitions of nine of these disciplines compiled by a National Research Council (NRC) study panel in the early 1990s. Only the three most popular IT-related disciplines—computer science, computer engineering, and information systems—will be considered here.

In a strict sense, computer science is focused on the study of algorithms, the software that implements them, the properties of computers, and the processes for creating these technologies. Computer engineering traditionally has focused on the engineering of the components and hardware systems that make up a computer. In this strict sense, it focuses on the underlying technology that implements computer hardware. Information systems, although less well defined as a discipline of study, has focused instead on the use of computer technology for end-purposes related to decisionmaking of some kind. All three of these disciplines capture some aspects of what we regard to be information technology, but none of them covers all aspects.

In the past decade, and even more rapidly in the past five years with the spread of the Internet, the rapid merging of traditional communications and computer-

Box 2-1

Undergraduate Degree Programs in Information Technology

Computer engineering - Graduates work primarily in computer hardware.

Computer science and engineering - Graduates work primarily in hardware, firmware, and software, depending on program and choices made by the student.

Computer science - Graduates work primarily in software design and implementation.

Software engineering - Graduates work with the engineering of software, with special attention devoted to large and critical systems.

Computer information science - Graduates work on the development of information systems, probably with more emphasis on information as an enterprise resource than is given in programs in computer science or software engineering.

Information systems - Graduates design, develop, implement, and maintain business information systems.

Management information systems - Graduates design, develop, implement, maintain, and manage information systems with a greater emphasis on the management of the systems than on the other aspects.

Information science - Graduates usually work in libraries or develop other facilities to provide information to users.

Source: Adapted from "U.S. Degree Programs in Computing" in *Computing Professionals - Changing Needs for the 1990s*, National Academy Press, 1993.

based systems has added to the confusion. Although most telecommunications technology has been computer-based for some years, the rapid miscegenation of the functionality of computers and of traditional communications systems has come to the forefront. The ability to make telephone calls over the Internet or make computations via a Web page devoted to a particular topic, or the provision of greatly increased content (such as bank account information) using a traditional telephone hookup, are examples. There is no precise boundary between information technology and telecommunications technology. Some cases, such as the provision of enhanced, computer-based information services as part of standard telephone service, probably should be considered information technology; others, such as installing telephone lines in homes or fiber cables under the ocean, may not be.

Who Is an IT Worker?

Defining an IT worker is complicated, not only because information technology itself is not clearly defined. A wide range of occupations might be considered IT work. They vary enormously in the technical and other skills required to do the job. These jobs are not located solely in the IT industry (the industry whose primary business is to make and sell IT devices, software, services, and systems), and they do not always involve the design and creation of information technology artifacts. Instead, they are distributed throughout virtually every sector of society, including government, all sectors of industry, and most nonprofit organizations; and they may involve many people who propose, implement, enhance, and maintain systems that rely upon information technology. Not every job in an IT company is necessarily IT work (Are the janitors at IBM IT workers? We think not). Many jobs involve some contact with information technology, but not all would be considered IT jobs; otherwise, this category would soon become so large as to be useless.

It is not surprising that the different studies of the IT worker shortage have employed different definitions. As the Department of Commerce report noted:[14]

What is an IT worker? It depends on whom you ask. In a broad sense, the term 'information worker' can be applied to data entry personnel, auto mechanics who use computer diagnostic equipment, medical technicians who operate CAT scan equipment, and loan officers who use computers to assess creditworthiness, as well [as] computer programmers, systems analysts, and computer scientists and engineers.

Commerce used the narrow definition of the Bureau of Labor Statistics classifications: computer scientists and engineers, systems analysts, and computer programmers. The Information Technology Association of America (ITAA) used a broader definition: any skilled worker who performs any function related to information technology, which itself is defined as the "study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware."[15]

The General Accounting Office (GAO) has noted how the lack of a good definition has caused problems in making good policy:[16]

The GAO and Commerce Department research into the IT industry labor issue reveals that it is necessary to make a distinction between the IT industry as a whole and the various occupations within the industry. This distinction is often overlooked or is not clear in the data; there is often difficulty in identifying people who are working in IT occupations if they are not working for an IT business. If one asks what government or companies should do about the IT labor issue,

[14] U.S. Department of Commerce, Office of Technology Policy, "America's New Deficit: The Shortage of Information Technology Workers, Fall 1997, p. 3.

[15] "Help Wanted: The IT Workforce Gap at the Dawn of a New Century," Information Technology Association of America, Arlington, VA, 1997, p. 9.

[16] Carlotta Cooke Joyner, "Is There a Shortage of Information Technology Workers?" Symposium Proceedings, The Jerome Levy Economics Institute of Bard College, June 12, 1998, p. 4.

the answers will be more apparent if the question is phrased more clearly. There is a substantial difference in salaries, employment opportunities, and labor supply by IT occupation. It is difficult to compare statistics that examine these issues because the studies use different definitions of occupations and therefore come up with widely different estimates of starting salaries, job vacancies, and labor supply.

An NRC report on computer professionals written in the early 1990s called for a simple classification scheme, which has yet to be supplied.[17] Jane Siegel from the Software Engineering Institute indicated:[18]

I would be thrilled if in the next major national surveys…they did nothing more than simply have a logical, simple structure that broke out people doing computer-related work…If I could get even very rough estimates of the degree field and some simple demographics about who these people are and a little bit about their turnover rate and what they do in life, I would have a whole body of knowledge that I think would help a large set of our users.

Alan Fechter from the National Academy staff, following up Siegel's suggestion, "cautioned that although a moderate level of detail may be valuable for corporate planning, a greater level of aggregation may be appropriate for purposes of national planning and estimation."[19]

This report will not attempt to provide the ultimate definition of an IT worker. However, two categorizations are presented that the study group believes can help with national planning and estimation. The first distinguishes IT workers from other kinds of workers who may sometimes use information technology in their jobs (see figure 2-2). Each IT-related occupation is located at a single point on the graph. As one moves from left to right, the occupations require increasing amounts of IT knowledge. As one moves from bottom to top, the occupations require increasing amounts of domain knowledge (knowledge of business practice, industry practice, technical practice, or other kinds of knowledge particular to an application domain). The diagonal line separates the IT-related occupations into two classes, depending on whether IT knowledge or domain knowledge is more important. If more than half the value provided by a worker involves his or her IT knowledge, then this person is considered to be an *IT worker*. If the person's occupation involves the use of information technology but it adds less than half the added value to the work, then we regard the person as an *IT-enabled worker*. A few occupations are plotted on the exhibit, as examples.

The second categorization focuses only on the IT workers. Table 2-2 differentiates four categories of IT workers, depending on the principal functionality in their occupation. The table includes

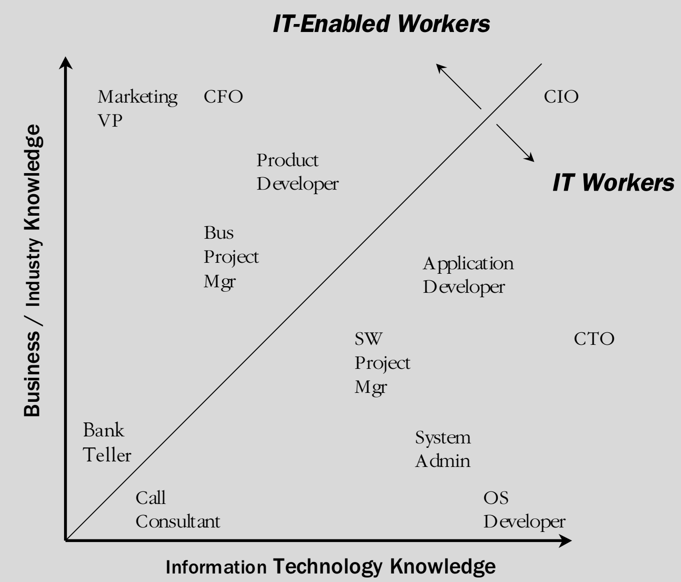
[17] The workers addressed in the NRC study—the "computing professionals"—probably constitute a slightly narrower class of occupations than are addressed in this study. National Research Council, *Computing Professionals—Changing Needs for the 1990's*, National Academy Press, 1993.

[18] Ibid., p. 18.

[19] Ibid.

Figure 2-2

Distinquishing IT Workers from IT-Enabled Workers



Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

examples of particular IT occupations that would fall under each of the four categories (conceptualizers, developers, modifiers/extenders, and supporters/tenders).[20]

This approach is somewhat different from the Standard Occupational Classification (SOC) scheme used by the Bureau of Labor Statistics (BLS),[21] in which the categories are essentially a distillation of job titles. This study found it difficult to classify workers on the basis of what they are called, at least in a way that is helpful to making policy. It decided instead to return to first principles and figure out what the workers do.

The categorization is built from a developmental perspective of the world. It is based on an experience and familiarity with the IT industry,

[20] Professor Daniel Papp of the Sam Nunn School of International Affairs at the Georgia Institute of Technology tested these categories in a survey of information technology education programs he conducted. He found that the respondents were able to use this categorization easily and that it seemed to have value for grouping the IT workforce issues occurring in Georgia. See Papp, "ICAPP Information Technology Strategic Response Educational Capabilities Inventory," draft report, December 16, 1998.

[21] The SOC categorization scheme was in the process of being updated in 1998, but it was not clear that the revisions would meet the criticisms lodged in this report. See Office of Management and Budget, 1998 Standard Occupational Classification Revision; Notice, *Federal Register*, August 5, 1998.

Table 2-2

Categorization of IT Jobs

Conceptualizers - those who conceive of and sketch out the basic nature of a computer system artifact:
- Entrepreneur
- Product designer
- Research engineer
- Systems analyst
- Computer science researcher
- Requirements analyst
- System architect

Developers - those who work on specifying, designing, constructing, and testing an information technology artifact:
- System designer
- Programmer
- Software engineer
- Tester
- Computer engineer
- Microprocessor designer
- Chip designer

Modifiers/Extenders - those who modify or add on to an information technology artifact:
- Maintenance programmer
- Programmer
- Software engineer
- Computer engineer
- Database administrator

Supporters/Tenders - those who deliver, install, operate, maintain, or repair an information technology artifact:
- System consultant
- Customer support specialist
- Help desk specialist
- Hardware maintenance Specialist
- Network installer
- Network administrator

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

where the workers are responsible for creating IT artifacts. However, this categorization should also apply reasonably well to all kinds of IT workers in all sectors of the economy (i.e., to those who develop, use, and maintain systems driven by information technology), and it should provide insight into current policy issues regarding supply and demand.

This belief is bolstered by the fact that there is a reasonably good match between level of formal education and category of worker. Table 2-3 maps formal education onto the four categories. There is not an exact one-to-one correspondence between educational degree and category of work. However, the exhibit clearly shows a correlation.[22] Occupations that fall under the conceptualizer category are commonly populated with recipients of master's or doctoral degrees. Occupations that fall under the developer or modifier categories are usually filled by people with bachelor's or master's

[22] This correlation breaks down, however, in the case of the earliest stage of conceptualization of an IT system, where the initial functional idea often comes from people with little IT education, but great applications knowledge.

Table 2-3

Typical Educational Preparation for IT Jobs	High School	Associate	Bachelor's	Master's	Doctorate
Conceptualizers	✓	✓	✔	**✔**	**✔**
Developers			✔	✔	✓
Modifiers		✓	✔	✔	✓
Supporters	✓	**✔**	✔		

Unlikely= (blank) Occasionally= ✓ Common= ✔ **Frequent= ✔**

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

degrees—and in the case of the modifier category, sometimes by people with associate's degrees. Supporter occupations tend to be filled most commonly with people holding an associate's degree, or perhaps only a high school diploma. Chapter 6 discusses at length the fact that an increasing percentage of IT worker training is provided outside of formal degree programs. This kind of training provides valuable knowledge of specific technologies, company culture, and the practices within that industry. It also hones skills such as communications, teamwork, and self-learning. However, there is some question whether it can adequately replace the foundational knowledge acquired in the formal degree programs, which is critical preparation for at least some IT occupations.

In this report, the term 'IT worker' is used throughout and always in the general sense described above. However, many of the sources cited either use alternative terminology ('computer professionals,' 'computer scientists,' 'computer and information scientists,' etc.) or they have a different meaning of 'IT worker' in mind. In these cases, the source's terminology is generally used, and an effort is made to clarify the intended meaning in the contextual discussion.

How Many IT Jobs Are There, and Where Are They Located?

Table 2-4 shows the number of IT workers in the United States and the annual percentage change in employment, using data from BLS.[23] Over the period 1988 to 1997, employment in the IT occupations (as they define them) grew from 1,259,000 to 2,063,000

[23] These statistics are taken and adapted from Exhibits 7 and 8 in Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Response," Draft Final Report, The Urban Institute, February 25, 1998.

Table 2-4

Numbers and Annual Change in IT Workers in the United States, 1988 - 1997

Year	Number of Workers (thousands)	Annual % Change
1988	1,259	–
1989	1,366	8.5
1990	1,411	3.3
1991	1,422	0.7
1992	1,435	0.9
1993	1,583	10.3
1994	1,687	6.6
1995	1,703	0.9
1996	1,863	9.4
1997	2,063	10.7

Source: Adapted from Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998, Exhibits 7 and 8. Based on the Bureau of Labor Statistics data.

jobs—a 64-percent increase. This can be compared with an increase of 29 percent in all professional jobs and an increase of only 13 percent in the total workforce during this time. Over this period, IT jobs increased from eight to eleven percent of all professional jobs in the United States, and from 1.1 percent to 1.6 percent of all jobs in the United States.

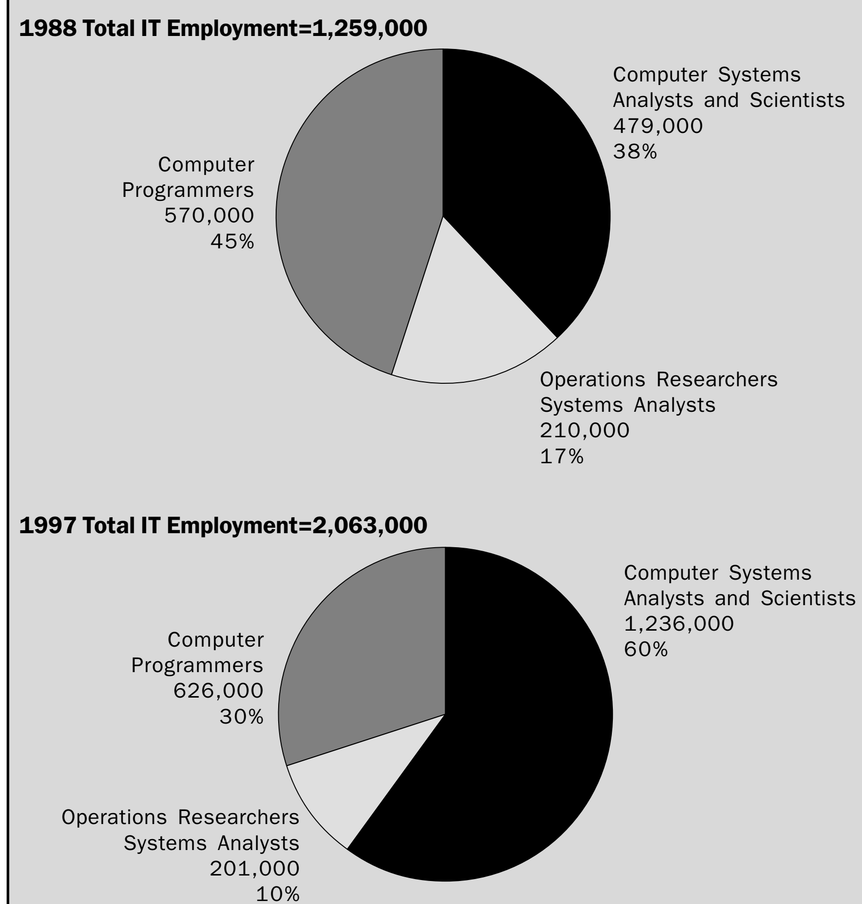
As figure 2-3 shows, the vast majority of IT jobs as reported by BLS are in one occupational category (Computer Systems Analysts and Scientists). Over the period 1988 to 1996, this category has grown much faster (158 percent) than the category of Computer Programmers (9.8 percent), while the category of Operations and Systems Researchers has dropped by 4.3 percent. From 1988 to 1996, the number of Computer Programmers dropped from 570,000 to 561,000, but in 1997 the number jumped to 626,000 (an 11.6 percent increase in one year). This may be an artifact of the temporary demand created by the Y2K problem.

The IT industry (that is, the collection of companies that produce IT products, services, or systems as their principal business) is one of the largest and most dynamic industries in this country. The number of workers in the computer and software industries has almost tripled in the past decade. However, this sector is by no means the only industrial sector in which information technology is being produced or used, or the only place where IT workers are employed. Indeed, there are IT workers in virtually every sector of American society. Information technology is rapidly being infused into the financial, retail, manufacturing, service, entertainment, transportation, and other industries; and numerous IT workers are going to work for companies in those sectors (see table 2-5 for some examples of the use of information technology in American industry). IT work also occurs in every geographic region of this country, not just in high-tech centers such as Silicon Valley or Route 128 in Massachusetts.[24] Thus a shortage of IT workers affects not only the IT industry (hardware, software,

[24] While there are IT jobs in every American community, there are also concentrations of IT companies in a number of locales. Silicon Valley is well known, but there are up-and-coming concentrations of IT companies and IT workers in a number of other places, such as Austin, Texas; Champaign-Urbana, Illinois; Salt Lake City, Utah; and the Washington, DC area. See Steven Levy, "The Hot New Tech Cities," *Newsweek*, November 9, 1998, pp. 44-56.

Figure 2-3

Comparison of IT Employment 1988 and 1997



Source: Adapted from Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998, Exhibits 7 and 8. Based on the Bureau of Labor Statistics data.

computer systems, computer services firms), but virtually every sector of the American economy.[25] The Y2K problem drives this point home. Computers are so firmly woven into the fabric of organizations that Y2K is a problem for almost every corporation and every government organization, and every member of society is affected.

[25] See, for example, *One Digital Day*, Intel, 1998, for a snapshot of the many applications of computing.

Table 2-5

Use of Computer Systems in the Operation of American Industry

◆ Inventory management by large retailers	◆ Control of manufacturing lines in the chemical and automobile industries
◆ Shipping scheduling and quality assurance by express courier services	◆ Processing data for oil exploration companies
◆ Financial controls in virtually every large business	◆ Global positioning systems used in the trucking industry and in scientific agriculture
◆ Frequent flyer programs by the airlines	◆ Literature searching in biomedical research
◆ Credit card validation by merchants	◆ Computer-aided design by engineers
◆ Production of movies and videos	◆ Automated switching in the communications industry
◆ Distance education	

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

What Skills Does an IT Worker Need in Order To Be Effective?

An effective IT worker needs a variety of skills, including technical knowledge about information technology, business knowledge and experience, and organizational and communications skills. The mix of skills needed varies greatly from one IT occupation to another. For example, a person doing IT work for a producer of household appliances will probably need to know more about production and accounting than an IT worker who is building general-purpose software utilities for a company in the IT or communications industry. It is impractical to present a complete set of skills needed for all IT occupations, or even for a single IT occupation. But it is possible to make a few observations, using examples from software-related occupations.

In the technical area, there are skills as well as knowledge to be acquired. A programmer needs to know how to design, program, test, debug, and modify programs. Someone specializing in operating systems would need to know how to analyze basic hardware operations and how to deal with complex communications situations. In the performance-testing area, a good knowledge of statistics is useful. A worker would need to know how to measure and analyze performance information and how to modify programs to improve performance. In the project management area, the worker would need to understand the project management model for code development and testing, be familiar with industry standards such as ISO 9000, and be able to establish requirements and functional specifications. In the project estimation area, a worker would need the ability to determine how long a project will take, what resources will be needed, and what dependencies on others need to be satisfied.

IT workers also need to have business skills and experience, which in many ways are similar to those needed by people in other service professions. Many workers need the ability to formulate project budgets, set tasks within those budgets, and complete work within time and budget. A worker may need to be familiar with specific application programs, such as corporate and industry databases, operation support programs, or manufacturing support programs. There is a need for knowledge about the specific application industry and its vocabulary, such as knowing who the leaders are and keeping up with industry standards. The worker needs to have knowledge of the customer's concerns and how to meet them; for example, how the customers use the IT product, their need for future products, and how current projects meet these needs. Finally, the worker needs to know the business practices of the employer: how projects are started, led, and terminated; the steps in getting a product to customers; and how customer needs are collected, distilled, and spread through the company.

IT workers also need communications and organizational skills, similar to those required of any worker involved in technical project development. There are teamwork skills, such as the ability to work with others who have diverse educations, skills, backgrounds, and cultures; to understand the function of each team member; and to respect the strengths and limitations of others. The worker needs to be able to organize and present technical material to technical peers, management, and customers. Non-technical skills relating to technical specifications and documentation—such as the ability to work in a team to design a project implementation, the ability to write a clear description of the job of each person on the team, and the management skills to delegate tasks within the team—are also required. The worker must be able to work to and revise specifications, and work to deadlines. Finally, the worker should be able accurately to estimate rates of progress towards goals and be able to report problems early. Table 2-6 shows that different kinds of IT jobs require different mixes of these technical, business, and communications skills.

Where does one acquire these skills? University programs in computer science traditionally have taught some of the technical skills, but not the business and communications skills (although students sometimes acquired some of these latter skills through internships). The accreditation bodies CSAB and ABET currently make communication skills a required component of an accredited computer science and computer engineering program, but the accrediting organizations do not specify the department that is to teach the skills or how they are to be applied. Indeed, almost no accredited program's department actually teaches communications skills as a separate course, although most of them require the application of these skills in some computing courses. These skills may not yet be emphasized as much as industry would like, but the trend is in the direction sought by industry. Business skills are not well addressed in computer science or

Table 2-6

Typical Knowledge, Skill Mix for IT Jobs (scale: 1-4)			
	Information Technology	**Business and Industry**	**Communication and Organization**
Conceptualiziers	4	2	3
Developers	3	2	3
Modifiers	2	3	3
Supporters	1	2	3

Scale: 1- least important; 2- moderately important; 3- important; 4- critically important.

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

computer engineering programs, but they are addressed in information systems programs.[26] Graduates in other majors generally gain less technical training, but often they get a better introduction to communications skills and even industry knowledge. Technical schools and self-help courses tend to focus on the technical skills. Corporate training programs often focus on all three.

Why Is Information Technology Becoming So Prevalent in Our Society?

There are many reasons why information technology has become so prevalent in the modern world, and there is no indication that these reasons will fade any time soon. The processing power and storage capacities of semiconductor devices, which are the building blocks of information technology, have been doubling every eighteen months for the past thirty years. At the same time, prices have continued to

[26] For an example of an attempt to introduce communications, teamwork, conflict resolution, and ethics into the information systems curriculum, see John Lamp, Chris Keen, and Cathy Urquhart, "Integrating Professional Skills into the Curriculum," http://www.man.deakin.edu.au/jw_lamp/acse-96.pdf ; also see "IS '97 Model Curriculum and Guidelines for Undergraduate Degree Programs in Information Systems," *The DATA BASE for Advances in Information Systems*, Vol. 28, No. 1, Winter 1997, ACM Special Interest Group on Management Information Systems (SIGMIS).

decrease. This means that information technology, which can be programmed to do practically anything, has become embedded in many kinds of organizational and physical systems. IT products have become commodity items. General-purpose semiconductor devices, such as the microprocessor, can now be used for millions of different purposes, leading to economies of scale. These devices are much more reliable than the mechanical, vacuum tube, and transistor devices that they replace. They add value to the products in which they are used, and they reduce the need for human users to do dangerous or boring tasks. Vast improvements over the past decade in the connectedness of computers and in human-machine interfaces have driven new uses.

What does this growing prevalence of information technology in society mean for IT labor issues? It appears as though information technology will be an increasingly important part of the U.S. national economy for many years to come. Although there are likely to be increases in productivity through new technologies and other means, the production of information technology will continue to rely on a large and growing force of workers who require high levels of skill and knowledge to do their jobs effectively. An inadequate supply of such workers will have harmful effects on the economy and the wealth of the nation. Any tightness in the labor market is likely to become a shortage within a few years, as the demand for information technology-based products and services grows. From a policy perspective, the focus needs to be not only on achieving a proper match between supply and demand today, but also on how the nation will supply the growing number of appropriately trained IT workers in the future.

What Are the Characteristics of Information Technology That Affect IT Labor?

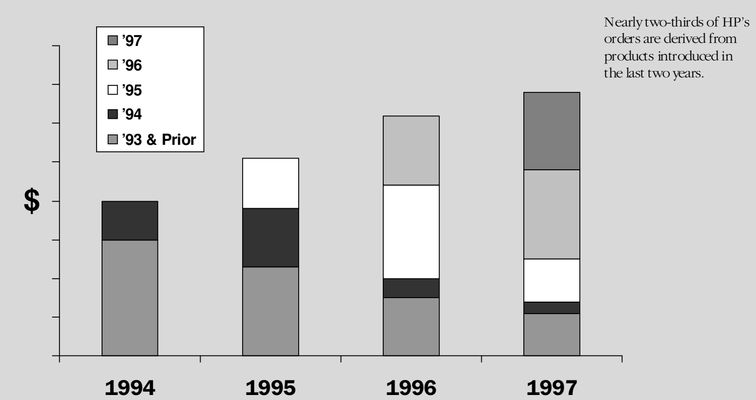
Information technology has a short life cycle. Figure 2-4 illustrates this short life cycle by charting the revenue earned by the Hewlett-Packard Company during four years in the mid-1990s. It shows that new products introduced in one year earn their greatest amount of revenue in the following year, and that by the second year after their introduction their contribution to the company's revenue stream has already diminished significantly. In fact, nearly two-thirds of Hewlett Packard's revenues are derived from products introduced in the previous two years. This is true of many other companies as well. The demands of competition, and the opportunities presented by technological advances, have driven the introduction of new products every few months, and an almost complete turnover of the product line in four years. This rapid turnover in technology makes it imperative that IT workers adapt to new technologies and new products. This means that they must continuously work at keeping their skills and knowledge up to date or risk becoming obsolete and unemployable.

The fluidity of the IT workforce gives labor a power over management. While some IT workers have gained knowledge

Figure 2-4

The Importance of New Products to Company Revenue

The Case of Hewlett Packard



Source: Hewlett Packard

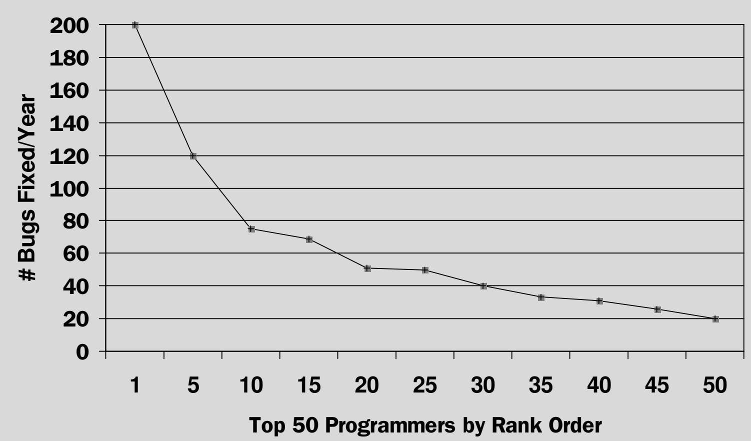
about particular application areas that represents a valuable asset in their work, there is nothing inherently application-specific about the information technology itself. Thus IT workers are not generally bound to specific industries. There is, however, a great variation in the productivity of IT workers. Especially in the software area, the best workers can be as much as ten times as productive as the least productive workers in the same company. Figure 2-5 presents one measure of this wide variation in the productivity of software workers. These kinds of variations occur among IT workers even when the labor market is not particularly tight. In a tight market, companies have to settle for less qualified programmers, and the effects of this variability in worker productivity may hit them harder. Companies may be fully staffed but nevertheless suffer greatly in productivity.

IT workers often have strong preferences about the kind of employer they wish to work for. Given the wide availability of jobs, many IT workers are more willing to change employers than are workers in many other occupations. They have little sense of being "locked in." Employers who are deemed less attractive because of the nature of their work, the salaries they pay, or the culture of their organization are more likely than other employers to experience IT worker shortages or to employ under-skilled IT workers. Figure 2-6 illustrates the hierarchy of employment. This is grim news for organizations at the bottom of the pyramid, which often includes government organizations.

IT work is stratified, and there is much greater demand for managers and other workers with system-level skills than for 'assembly line' programmers. The "average annual level of change in employ-

Figure 2-5

Variability in Programmer Productivity



Source: "Not all Programmers Are Created Equal," G. Edward Bryan, IEEE, 1994.

ment for computer systems analysts, engineers, and scientists was in excess of 10 percent, well above the 1.2 percent" for computer programmers.[27] Managers and more advanced IT workers require a longer time to train, both through formal education and on-the-job experience. Consequently, there will be longer lags in responding to changes in demand for these more highly skilled workers.

[27] Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998.

Figure 2-6

Who's Getting the Top Talent?

Tier 1 - Hot Software Companies

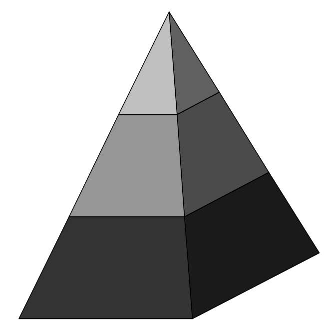
- Software start-ups and boutique service firms
- Software publishers
- Wall Street
- R&D (corporate and university)

Tier 2 - Software-aware Companies

- VARs, consulting firms, systems, integrators
- Software intensive industries (computer hardware, communications, financial services)
- Aerospace systems firms

Tier 3 - Everyone Else

- Other industries with incidental software
- Most IS applications development and maintenance
- DoD, federal, state, and local governments



Source: Stanford Computer Industry Project, 1999.

What Are the Dynamics of the Marketplace and the Dangers of Government Intervention in the IT Labor Market?

In most industries, there are boom and bust cycles that affect the respective labor market. Even the IT sector, which overall has had a rapid upward growth for the past half-century, has experienced economic downturns. It is common in any active profession to have occasional mismatches between labor supply and demand because business cycles tend to move up and down more rapidly than changes in supply. Occasionally, supply changes more rapidly than demand, as shown by the growth of 40 percent per year in newly declared computer science majors at research universities the past two years. The invisible hand of the marketplace will often correct for shortages through wage pricing and other adaptations. Especially when there are many employers vying for the labor pool, wages will typically rise enough to attract workers from other fields. Government intervention in a market is generally regarded as advisable either when the free market is unable to operate on its own, or where the costs are regarded as too high. Examples of these costs are the long time it takes for the market to self-correct, the pain caused to individuals or institutions, or risk placed on the national economy or national security. In fact, it is very difficult for government organizations to effectively control labor supply—not to mention that there is little political will for doing so in this era of free markets. It is hard to predict future demand and to collect timely data about the effect intervention is having; as a result, it is easy to over-stimulate a labor pool.

Even when wages rise, the market cannot adjust more quickly than the amount of time it takes to train an adequate supply of workers. In the IT sector, such delays are often quite short. Anecdotal evidence suggests that it takes about six months to retrain a worker for a low- or mid-level IT occupation, assuming the worker already possesses some basic skills on which to build. Some high-level positions, such as management positions or senior research positions in laboratories, may require a longer training period. Sometimes, instead of a shortage occurring immediately, the level of talent filling open positions is gradually lowered. This may be especially true for particular segments of the labor market—for example, a geographic region, employers who have a rapid increase in demand, or companies that are regarded by workers as somehow less attractive as employers (e.g., because of the nature of the work, the wages paid, or the corporate culture).

The recent history of intervention by U.S. government agencies to meet perceived shortages of scientific and technical workers does not provide an encouraging picture. Perhaps the most notorious recent case of failed policy pronouncements is the warning during the late 1980s from then-senior management of the National Science Foundation (NSF) about looming 'shortfalls' of scientists and engineers. These warnings were based on methodologically weak projection models of supply and demand that were originally misinterpreted as credible forecasts, rather than simulations dependent upon certain key assumptions. The projections yielded numerical estimates of the shortfalls anticipated, eventually reported to be 675,000 scientists and engineers by the year 2006.

Based in part on these worrying pronouncements, Congress agreed to increase funding for NSF science and engineering education programs. Several years later, in 1990, again influenced by the shortfall claims, Congress agreed to greatly expand the number of visas available for foreign scientists and engineers, for both permanent and non-permanent residents. (This bill was the origin of the H-1B visas, among other measures.) Many educational institutions moved to increase the numbers of graduate students in these fields. By the time these larger cohorts of graduate students emerged with their newly earned doctorates, the labor market in many fields had deteriorated badly, and many found their career ambitions extremely frustrated. This experience proved embarrassing, leading to congressional hearings in 1992 and harsh criticism of NSF management from several prominent congressional supporters of science and engineering. A repetition of this experience should be avoided in handling the IT labor market.

What Factors Limit the Ability of the Government, Industry, University System, and Professional Community To Improve the Match Between Supply and Demand?

It may be difficult for companies to recognize that there is a worker shortage, especially if they employ only a few workers in a given IT occupation, or if they are used to taking a long time to fill vacancies (which is common for positions that require a high level of education or training or many years of experience, even in times of market equilibrium). But even if the government, industrial, and academic sectors do recognize that there is an IT worker shortage and decide they want to deal with it, there are factors that limit their ability to do so. The high level of competition and the short product life and product development time often make it difficult for companies to hire new employees who require a lengthy period of break-in training before they can become productive. It also makes it difficult to retrain an existing employee for a significantly different job. Thus companies are sometimes forced, by competitive pressures, to lay off workers of one type and hire workers of another type. Or they may refuse to hire anyone who does not already possess all the needed skills. These employer practices receive harsh criticism at times from labor unions and some government officials, but to some degree this is a rational and perhaps necessary reaction to the realities of the marketplace.

Universities are sometimes criticized for their slow response to market conditions and their reluctance to allocate or reallocate resources to programs with high and growing demand. Perhaps most importantly, it should be noted that the colleges and universities do not control student demand. In this free market, student demand can change quickly—certainly more quickly than most universities can react. It should also be remembered that most universities have limited resources, most of which are tied up in long-term commitments such as buildings and tenured faculty. It is difficult for universities to shift tenured faculty from one subject area to another—especially from one department to another, but often even within a given department. Even when such shifts do occur (such as library science faculty becoming management information science faculty) these faculty retreads are often not accepted as full citizens, they may never conduct the kind of research that fits into the new department, and they may not provide good leadership in the new area. However, they do take up faculty slots that might have been assigned to a young researcher trained in the area. Part-time and adjunct appointments are one tool that departments can and do use to respond to rapidly changing market conditions. But a commitment to build up a computer science or information systems faculty (other than with non-tenure-track faculty) means making a long-term commitment, which is almost certainly made at the expense of some other worthy initiative.

The slow response is also partly due to the decision and review process. This process often seeks out views on major initiatives from many parts of the university—faculty, administration, and sometimes even students and staff. This deliberative process, which largely precludes a response time that can keep up with industry trends, is part of what universities believe gives them strength. Industry, however, often sees this operating style as a weakness.

There are various factors that limit the government's ability to act. Supply and demand are not regulated by the government; the government can only offer incentives to encourage a student to study a particular field or a company to broaden its hiring practices. It is hard for a government to stimulate labor supply in any discipline by just the right amount: the market is constantly changing, the information about supply and demand is imperfect and is difficult to obtain in a timely fashion, and it is hard to predict the effects that a government initiative might have. Another factor involves state and local versus federal rights. Educational issues, especially at the K-12 level, are considered primarily a local prerogative; but national labor issues require national action, or at least national coordination, of K-12 and higher education. Government organizations also have a limited ability and desire to interfere with the actions of a private organization, such as a company or a university.

For all of these reasons, even when there is a desire to act, there are often impediments to doing so.

What Are the Costs of an IT Worker Shortage?

A substantial shortage of IT workers can incur many different costs. The effects are felt on many levels—the nation, various industries, individual firms, and consumers:

- A shortage of skilled IT workers in the IT industry and other high-tech industries would slow innovation and product development, which in turn would harm exports and wealth creation in the United States.

- Industries dependent on IT workers would grow more slowly if there were an IT worker shortage, and this would have a negative impact on employment overall.

- American companies might become less competitive globally because the up-push of salaries in a tight labor market would have to be reflected in the prices of goods and services produced, or because these companies could not get their products on the market as rapidly as foreign companies that are fully staffed.

- If American talent were too expensive or in short supply, companies would be more likely to move jobs offshore.

- Companies with intensive or company-critical IT functions that were unable to find an adequate supply of qualified IT workers might have to merge with companies that have these talents. While a merger is not a bad thing in and of itself, industry concentration for the purpose of acquiring expertise might harm economic forces and industry efficiency.

- Information technology is leading to enhanced productivity in a number of industries. A lack of IT workers would lead to a slowdown in productivity improvement.[28] When salaries are driven up, certain kinds of organizations might

[28] In the early 1990s some economists questioned the productivity added by information technology, but this attitude seems to be changing, coming into line with long-standing anecdotal evidence that this technology can provide significant productivity gains.

be less able to meet industry market salaries and would be affected disproportionately by the shortage of workers. This has been true, for example, of government organizations trying to fix their Y2K problems. This factor has also affected the ability of universities and other nonprofits to attract qualified IT talent.

◆ IT graduate students and faculty might be attracted away from universities in sufficient numbers to jobs in industry that there would not be an adequate number of teacher-scholars left to train the next generation of IT workers (the so-called "seed-corn" problem).

◆ A shortage of skilled people would mean that in some cases employers would fill positions with people who are less than adequately qualified. This practice could lead to poorer performance, high rates of project failure, a slowdown in delivery, and decreased innovation.

◆ Software projects, especially large ones, already have a high failure rate (perhaps an artifact of a long history of inadequate numbers of well-trained IT workers). This would likely worsen with a shortage of skilled IT personnel.

◆ Tight labor markets are often characterized by "churning," the increased movement of the employees from one employer to another. Churning significantly increases recruitment and retraining costs for employers; it also means that the time of technical staff, as well as management and human resources staff, is spent on recruiting, retaining, and retraining employees, rather than on more productive elements of the business.[29] New employees are not as productive as employees who have been with a company for some time because new employees need to learn about company projects, processes, skills, and capabilities.

◆ Workers who are responsible for conceptualization and development lose productivity when there is a shortage of adequate support staff and adequately maintained support systems.

◆ When there is a shortage of staff, employees who might have been assigned to create new products sometimes are reassigned to maintain existing products or company support systems. This could limit innovation and stifle competitiveness.

◆ There could be a reduction in the range of products available to both individual Americans and to American companies who use them to improve their own products, services, and well-being.

What Are the International Considerations in Dealing with a National Worker Shortage?

The IT marketplace and the companies in it are increasingly international in scope. Virtually all of the major companies in the IT

[29] For a reflective article on the issue of job churning, see Robert W. Lucky, "Job Churn," IEEE *Spectrum*, November 1998, p. 17.

industry headquartered in the United States offer their products and services around the world. Most have sales offices in many countries, and some have factories and even research laboratories outside the United States. Beginning in the 1970s, American companies began to increase their use of overseas workers to manufacture components and assemble products, as labor costs escalated in the United States. Similarly, IT companies headquartered in other countries have opened foreign offices as they try to expand their markets. A few foreign IT companies have established a substantial presence in this country, and a number of both European and Japanese companies have established IT-related research laboratories here (e.g., Hitachi, Mitsubishi, NEC, Panasonic, Philips, Ricoh, Sharp, Siemens, and Sony).

This means that there is increasing worldwide competition for IT contracts; if U.S. companies cannot provide the service and products, increasingly there are other options. This surely could lessen the demand for IT workers in the United States; but it could also prove to be an opportunity for U.S. companies to build up their world business. It was long thought that American industry would maintain control of both the national and worldwide IT industries because of its large civilian and military domestic markets, strong higher educational system, good research laboratories, and domination of software development. But there have been pressures against the American companies. For example, in the 1980s, a globalization of the software industry began, driven by a search for talent. So far, the United States still dominates the software industry, perhaps because the capacity of foreign labor sources is strictly limited by the numbers of highly educated individuals and by the educational infrastructures in other countries. However, it is hard to know how long this domination will last.

The flow of IT work and workers is not limited by national boundaries. It is not uncommon for IT workers from one country to work for a few years or even their entire careers in another country, although no statistics are available on the numbers. Anecdotal evidence indicates that the United States is by far the destination of choice for IT study and work. Roughly half the graduate students and one-tenth of the undergraduates in IT-related departments are foreign nationals; and foreign-born students who earn science and engineering (S&E) doctoral degrees from U. S. academic institutions are staying in this country after graduation in increasing numbers. A recent NSF study indicates that 63 percent of foreign-born students who earned S&E doctorates from U.S. institutions between 1988 and 1996 said they planned to locate here, compared to 50 percent or less of those previously studied. Two-thirds of those who planned to stay had firm plans for further study or employment.[30]

One might think that the influx of workers and students would help meet the strong demand by American companies for IT workers. Indeed, it does help. However, it is fairly clear that

[30] See "Statistical Profiles of Foreign Doctoral Recipients in Science and Engineering: Plans to Stay in the United States" (http://www.nsf.gov/sbe/srs/nsf99304/start.htm)

foreign sources of labor is not the long-term solution to IT labor needs in the United States. The supply of foreign workers is limited by numbers, resources, government policies, and demands for them in their home and other countries. A number of countries are reporting their own shortages of IT workers and are placing pressures on or providing incentives to their indigenous IT workforce to stay at home or return home. These countries are also in competition with the United States for workers from those few countries, such as India, that have a surplus of IT workers.[31]

[31] Some examples of reports on IT worker shortages and worker levels in countries other than the United States:

Canada: "Software and National Competitiveness, 1995 Update," Software Human Resource Council. (hard copy). Also see http://www.shrc.ca/index.html; Update to the Human Resource Study of the Software Industry, Human Resource Development Canada, 1995 (hard copy), but also see http://www.hrdc-drhc.gc.ca/hrdc/corp/stratpol/arbsite/research/rsctoc_e.html and http://www.hrdc-drhc.gc.ca/hrdc/corp/stratpol/arbsite/publish/bulletin/contents.html)

The Netherlands: Advisory Council for Science and Technology Policy, Report 31. The structural need for computer scientists, February 1998. (PDF, in Dutch) Also see http://www.awt.nl/en/advlist.html

India: "The Software Industry in India 1997-98: A Strategic Review," NASSCOM, Also see http://www.nasscom.org/ and A. Barr and S. G. Tessler, "The Globalization of Software R&D: The Search for Talent," http://www-scip.stanford.edu/scip/avsgt/cfr1296.pdf and "Software R&D Strategies of Developing Countries," http://www-scip.stanford.edu/scip/avsgt/cfr197.pdf

United Kingdom: "Skills Alliance Lists Projects That Need Help. *Computerweekly (UK)* article about study sponsored by Department of Trade and Industry. http://www.computerweekly.co.uk/news/20_11_97/08622625264/C6.html

Israel: "Information Technology in Israel: Human Capital & IT." Gives a count of IT workers only: http://gurukul.ucc.american.edu/mogit/dz9586a/humapage.html. Forecast of a shortage (article refers to study done by Ministry of Industry and Trade): "Israeli Software Firms Meet Needs by Training, Hiring Yeshiva Pupils," *Jerusalem Post Service*, http://www.jewish.com:80/bk970919/ifirms.htm

Belgium: Insea (a Belgian professional association) report (1997) counts the number of Belgian workers and forecasts worker shortage and spiraling wages. "Informaticiens Rois."

Worldwide headcount: Several years ago *The Economist* offered a chart of the number of software workers in various countries, based on some estimates of the META group. These numbers were not necessarily based on government reports by country, but are a starting point. "The Importance of Being American" (from Survey of the Software Industry) *The Economist*, May 25, 1996. Counting new graduates entering the workforce (outside of the US) is even tougher. But productivity and headcount are two different things. There are estimates of two million for the number of technical professionals in Russia, but their productivity is inhibited for a number of reasons. Some of those reasons are mentioned in A. Barr and S.G. Tessler, "Software R&D Strategies of Developing Countries," http://www-scip.stanford.edu/scip/avsgt/cfr197.pdf

How Does One Determine Whether There Is a Labor Shortage?

Part of the controversy surrounding information technology (IT) workers stems from the fact that there is no definition of the term 'labor shortage' that is universally accepted. What one person might consider a labor shortage another might regard as only a "tightness" in the labor market, and a third person might dismiss the question entirely because of the way in which the supply and demand categories were defined. This report uses the Department of Labor's definition of shortage: a "market disequilibrium between supply and demand." A shortage requires two things: an occupational market in disequilibrium and a slow market response. Alternative definitions of labor shortage are provided in sources cited in the footnotes.[32]

When a worker shortage occurs, employees and workers take various actions, some of which can be tracked statistically as indicators of the presence and severity of a shortage—even when one cannot measure supply and demand directly. These indicators include: vacancy rates, amount of employment change (so-called 'churning')

[32] For a description and analysis of various definitions of 'labor shortage' given by economists over the past forty years, see Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998, pp. 4-14. One definition in particular that we do not adopt is the so-called Social Demand Model of labor shortage. Under this definition, a shortage exists if there is not a sufficient number of workers of the type in question to meet a particular social goal. Thus some people might argue that there is a shortage of public school teachers because children seem to get a better education in smaller classes; or others might argue that there is a surplus of lawyers because our society would be better off if it were less litigious. The Social Demand Concept of a shortage depends on personal judgments about social welfare. The definition we adopt focuses on market equilibrium—the match between supply and demand as measured by economic indicators.

from firm to firm within the labor market, unemployment rates, changes in wage rates, predicted employment growth, and demand for foreign workers as indicated by labor certifications.[33] In general, the presence of multiple indicators provides better assurance that a shortage exists. Perhaps the most commonly used indicator of a labor shortage is vacancy rates. Unfortunately, this indicator can be misleading. Vacancies occur in labor markets that have supply-demand equilibrium, and even in markets where there is a surplus of workers. Vacancies occur because of normal turnover and lags in filling open positions; indeed, they are a natural part of any business operation. One large company in the IT sector reported to the study group that it regards vacancy rates of five percent as normal—a management decision driven by the flexibility needed to fill positions quickly when the need arises in this rapidly changing field.

There are many kinds of shortages. They may be specific to one geographic region, or to a particular set of occupations or subspecialties within a labor market. They may be episodic (e.g., created by a one-time phenomenon of limited duration, such as the Y2K problem or the Euro conversion) or more enduring.

There may be non-statistical indicators of a labor shortage as well. If a large number of people say there is a labor shortage problem and act as though there is, then there may well be a problem. This is especially true if the action comes from companies ranging across multiple geographic regions and industry sectors, and if these companies begin to devote significant resources to correcting the problem by increasing recruiting, initiating studies, supplementing training, or even lobbying. A further indication of a shortage is when labor suppliers and professional societies representing the workers, not only the trade associations representing the companies, become concerned.

Is There a Shortage of IT Workers?

For some readers, this is the most important question addressed in this study. It is difficult to give a straightforward answer because of the imprecise definitions of supply and demand, the complexity of the IT workforce (many different kinds of jobs involving widely varying skill and knowledge sets, and distributed across many different sectors of the economy), and the lack of good data. There might be a shortage in one IT occupation (such as LAN administrators), but not in another (such as data entry clerks); or in one geographical region (such as Silicon Valley) and not in another (such as a purely agricultural area). The situation also changes rapidly over time. What is true at the time this report is written may not be true six months later.

In trying to answer this question about a shortage, it would

[33] See Barnow, Trutko, Lerman, ibid., p. 55, for a discussion of this issue. Also see Timothy Bresnahan, "Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-level Evidence," Department of Economics, Stanford University (http://timb.stanford.edu/research/itwold8-21f.pdf)

probably be more insightful to do some labor market segmentation, rather than viewing the IT labor pool as one undifferentiated mass. There are barriers to geographical relocation of workers, which might make geographical segmentation useful. These include the cost of relocation, the cost of living in some of the areas where IT jobs are abundant (e.g., Silicon Valley), the social upheaval to the worker and the worker's family, and the difficulty of locating and securing a job outside the region where the worker is currently living. Distance may be a particular barrier in filling lower-skill, lower-pay jobs. Thus geographical segmentation of the IT workforce may be important to the understanding of shortages.

Because the skills and knowledge required vary so much from one IT job to the next, occupational segmentation may be even more useful than geographical segmentation. It would be a good test of the analytical value of this report's categorization scheme to segment the labor pool into conceptualizers, developers, modifiers/extenders, and supporters/tenders to segment the workforce when looking for labor shortages (see table 2-2). It is clear, however, that such a segmentation would not provide a complete breakdown. For example, computer security and networking are hot areas today, and there may well be shortages, or at least very tight labor markets, associated with these specialty areas. However, they cut across our four categories. The demand is uneven across even a single occupation, such as programmer. There is no known demand for APL programmers today; COBOL programmers are in short-term demand for fixing Y2K problems; and Java programmers appear to be in demand for the foreseeable future because of all the network applications being written in Java. Unfortunately, the data are inadequate to support a segmented analysis by either geography or occupational categories; thus this discussion of the shortage issue will consider the entire IT workforce.

At the outset of this study, it was clear that some trade associations believed there was a shortage of IT workers, while some labor unions disputed the claim. The H-1B debates showed that the worldviews and interests of these two kinds of organizations made it difficult to find common ground on which to evaluate the question of a worker shortage. The study group was somewhat surprised and dismayed to find a similar gulf between IT professionals and social scientists interested in this issue. The IT professionals have what they believe to be overwhelming local evidence of a shortage—personal experience of multiple unfilled jobs, multiple job offers for their graduating students, high salaries for graduates in hot technology areas, and more. The social scientists, trained to discount this kind of anecdotal evidence, demand strong statistical proof. As part of their scientific training, they tend to be skeptical about virtually all of the existing statistical data, which is in one way or another imperfect; and they tend to dwell on the methodological shortcomings of the data rather than using them as predictors—albeit imperfect ones—of a shortage or lack thereof.

Where (most) IT professionals see a shortage, (most) social scientists see a tight labor market.

Is this just a semantic difference? This is unlikely. The distinction reflects an attitude about the nature of the problem and the need for a policy response. If there is simply a tightness in the labor market, there is a belief that the costs are bearable to the market participants, the market will eventually self-correct (or market participants will learn to live with the situation), and no government intervention is necessary. If there is a shortage, however, the costs to the market participants may be unbearably high, the ability of the market to self-correct is questioned, and government action may be warranted.

Unfortunately, no one kind of evidence currently available provides a clear and unambiguous answer as to whether there is a shortage—or even a tightness—in the IT labor market. Thus the strategy in this section is to look at six different kinds of evidence, each with its own strengths and weaknesses: 1) a direct counting of supply and demand; 2) secondary statistical indicators based on presumably solid federal data; 3) data from limited-scope studies that seem to be methodologically sound; 4) data from more general studies whose methodologies have been questioned; 5) anecdotal evidence of employer actions; and 6) other qualitative evidence. The limitations of each kind of evidence are discussed, as well as what it indicates about the existence of a shortage/tightness.

1. Direct counting. In order to demonstrate that there is a shortage of IT workers—that is, an excess of demand over supply—one would need a clear working definition of an information technology worker, as well as good statistical data about supply and demand. The problems of finding a good working definition of an IT worker have already been discussed. The supply system is complicated, as chapters 5 and 6 show; and anything close to adequate statistical data about the current potential supply, much less future supply, are nonexistent. Data about demand are even more elusive—they are out of date, the sample sizes are too small, and they rely on vague and inconsistent definitions of what kinds of demand to count as related to IT workers. ***Thus it is impossible at this time to provide meaningful quantitative information about a national shortage of IT workers.*** In particular, there is no adequate basis for quantifying the size of the shortage (if there is one). Collecting better data will be a major challenge, and the study group is not optimistic that reliable quantitative measures are likely to be available anytime soon.

2. Statistical indicators based on federal data. Even if the supply-demand match cannot be measured directly, it is useful to look at four secondary data indicators based on federal data. These data are likely to be as reliable as any data available on this issue because of the size and scope of federal data sets, the objectivity with which the government collects the data, and the methodological rigor with which they are analyzed. These secondary data indicators provide only inferential, not direct, evidence of a shortage; and for each indicator, there are some reasonable questions that might be raised about the validity of the inference. In general, these secondary indicators are also unable to distinguish between a shortage and

Table 4-1

Unemployment Rate for IT Workers, 1988 - 1996, Based on Current Population Survey (CPS) Data

Year	Computer Systems Analysts & Scientists	Operations & Systems Researchers & Analysts	Computer Programmers	All Professional Specialty Occupations	All Workers 16 years & older
1988	1.4%	2.2%	2.9%	1.7%	4.9%
1989	1.4	2.8	1.6	1.7	4.7
1990	1.5	1.3	3.0	2.0	5.0
1991	2.6	3.2	3.5	2.4	6.2
1992	2.7	2.0	3.1	2.6	6.8
1993	3.1	1.9	2.7	2.6	6.2
1994	1.8	2.7	2.1	2.5	5.7
1995	1.9	1.5	1.8	2.5	5.2
1996	1.3	1.2	1.6	2.3	5.0
1997	1.1	1.4	1.6	2.1	4.5

Source: U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, Household Data, Annual Averages (published in January after each year).

a mere tightness in the labor market. While none of the indicators provide conclusive evidence, taken together they offer a preponderance of circumstantial evidence in support of tightness/shortage in the IT workforce.

◆ *Unemployment rates.* As table 4-1 shows, the unemployment rates for each of the three categories of IT workers under the Bureau of Labor Statistics (BLS) classification system were all 1.6 percent or lower in 1997. The IT unemployment rates are about three times as low as overall unemployment rates in the United States—suggesting a shortage/tightness. However, to properly interpret these numbers they should be seen in comparison with some other statistics. First, the IT unemployment rates have been consistently low, in both absolute terms and in relationship to national unemployment rates, since 1988; however, the claims for an IT worker shortage have only been made in the past several years. Why were they not made in the late 1980s or early or mid-1990s? Second, it may be unfair to compare IT unemployment rates with national unemployment rates, in that professional unemployment rates are almost always significantly lower. The overall unemployment rate for all specialty professions is only slightly above two percent—not that much different from the IT worker unemployment rates. But it is hardly credible that there is a shortage of all professional workers. Thus, while unemployment rates may suggest a shortage/tightness in the IT labor market, as an indicator they are not entirely unproblematic.

◆ *Permanent labor certificates.* Certificates offered by the Department of Labor represent another indicator of demand unmet by domestic workers. Aliens who want to become permanent residents must have an offer of permanent, full-time work from an employer in the United States. The employer must obtain a labor certificate from the Department of Labor, indicating that qualified U.S. workers are not available for the position, and that the wages and working conditions are consistent with prevailing conditions for similar employment in the United States. In 1996, about

40,000 new applications were received and a slightly larger number were approved. About eleven percent of the approved applications were for IT-related occupations. Three IT occupations were among the five occupations receiving the largest number of permanent labor certificates in 1996: software engineers (ranked second, behind specialty foreign cooks, with 2,238 approvals (5.5% of the total)), programmer analysts (ranked third with 1,231 approvals (3.0 %), and systems analysts (ranked fifth (after college and university faculty, with 616 approvals (1.5%)). Other IT occupations ranked in the top 100 were: computer programmers (124 approvals), database design analysts (104 approvals), computer systems hardware analysts (74 approvals), database administrators (69 approvals), systems programmers (56 approvals), and programmers—engineering and scientific (45 approvals).

There are several arguments against using these permanent labor certificates as a strong indicator of IT labor shortage/tightness. While the IT occupations rank high in the list of occupations for which permanent labor certificates are requested, the absolute numbers are small. Some even question how meaningful these statistics are. Anecdotal evidence from computer industry executives suggest that many of these certificates are applied for (and more than 90 percent are approved) not to fill an unfilled job, but at the request of a current employee who is working on a temporary visa (H-1B or one of the predecessor programs) who wants to work permanently in the United States. The Department of Labor's Inspector General has reported that the certification program is subject to extensive manipulation by employers and immigration lawyers.[34]

◆ *Temporary labor certificates.* Department of Labor certificates are also available for employers who wish to hire professional workers under the H-1B visa program. Employers must certify that they will pay the prevailing wage and that there is no strike or lockout underway. There is no limit on the number of job openings that can be filed for certification, and the Department of Labor approves almost all of them. However, there is a limit on the number of H-1B visas that can actually be awarded in a given year. In 1996, 41.6 percent (102,422 out of 246,725) of the applications were for IT-related jobs. In fact, the most frequent occupations for which H-1B labor certificates were received (84,370 jobs, representing about one-third of all jobs certified), were in Systems Applications and Programming. The large number of these H-1B labor certifications suggests a shortage/tightness in the domestic labor market. Although many of these certificates are apparently awarded to foreign-owned companies operating in the United States that hire primarily foreign workers (e.g., Tata Consulting, Syntel, or Mastech), these companies are still undertaking IT work for U.S. industry, helping to satisfy the overall demand. Hence, even though special kinds of companies may dominate the requests for these certificates does not mean that this information should not be factored in.

[34] See http://www.oig.dol.gov/public/reports/oa/1996/foreign-labor-cert.pdf.

Table 4-2

Earnings and Change in Earnings for IT and Other Workers

Type of Job	Median Weekly Earnings ($) (1997)	% Change in Salary 1988 - 1997	% Change in Salary 1996 - 1997
Computer Systems Analysts and Scientists	918	36.2	3.0
Operations Researchers/ Systems Analysts	867	28.4	6.4
Computer Programmers	840	42.9	8.8
All Professional Occupations	750	35.1	2.7
All Workers with 4 or more years of college	779	33.2	2.8
All Workers 16 years old or older	503	30.6	2.7

Source: Adapted from Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998, Exhibits 13 and 14. Based on the Bureau of Labor Statistics data.

◆ *Wage growth.* Table 4-2 shows that salaries in the IT-related occupations have gone up at about the same rate as, or only slightly faster than, salaries in other professional occupations—or than salaries overall. This fact suggests there is no shortage, contrary to all of the other statistical indicators based on federal data described above. One possible explanation is that BLS data on wages are inconsistent with private sources of data, such as employer salary surveys. The private data sources virtually all give annual wage growth figures that are higher than federal data—including one source that shows an annual wage growth of 18 percent in some IT occupations.[35] The trade association Information Technology Association of America (ITAA) claims the reason for this is that "BLS numbers do not include stock options, signing bonuses, and referral bonuses, which are major parts of compensation packages in the IT industry."[36] However, the case of the systems administrators suggests another possible explanation for slow wage growth. Whenever there is a rapid growth in an occupation, the average level of experience is likely to fall. In some IT occupations—such as systems administrators—there are a large

[35] However, some of the recent non-federal data show a flattening of salary increases. See the 12th annual salary survey by *Computerworld* and the related article by Leslie Goff, "Enough is Enough: The Joyride Is Over, As Corporate Managers Put the Brakes on Out-of-Control Salaries for IT Professionals," *Computerworld*, September 7, 1998 (http://www.computerworld.com/home/features.nsf/all/980907mgt)

[36] Lauren Brownstein, "Is There a Shortage of Information Technology Workers?" *Symposium Proceedings*, The Jerome Levy Economics Institute of Bard College, June 12, 1998, p. 5.

Table 4-3

IT Occupations with Anticipated High Job Growth 1996-2006			
	Employment (thousands)		
Type of Job	1996	2006	% Change
Database Administrators, Computer Support Specialists, and all other Computer Scientists	212	461	118
Computer Engineers	216	451	109
Systems Analysts	506	1,025	103
Desktop Publishing Specialists	30	53	74
Data Processing Equipment Repairers	80	121	52
Engineering, Science, and Computer Systems Managers	343	498	45

Source: Bureau of Labor Statistics, *Monthly Labor Review*, November 1997.

number of workers at the entry level, apparently meeting a need at that level; however, there may be a serious shortage of workers with the same job title but having advanced skills.[37] While the average salary for systems administrators did not rise much in the period 1989 to 1993, salaries for high-end systems administrators (at least in the San Francisco Bay area) doubled.[38] In such cases, it might be more revealing to track top-quartile salaries or conduct a longitudinal study of salaries of a particular group of workers, rather than rely on average occupational salary. It is not clear how representative this example of systems administrators may be of IT work as a whole.

◆ *Worker projections.* Table 4-3 shows IT occupations that appeared in the table of Occupations with the Largest Job Growth, 1996-2006, produced by BLS. The joint category of "database administrators, computer support specialists, and all other computer scientists" appeared at the top of the list, with an expected growth rate of 118 percent. Computer engineers and systems analysts came second and third on the list. Also appear-

[37] This example is not one discussed in the ITAA report. For an interesting overview of the occupation of systems administrator, including a description of the job and formal educational, commercial training, and independent study programs preparing a worker for this occupation, see David Kuncicky and Bruce Alan Wynn, "Educating and Training System Administrators: A Survey," published by the USENIX Association for SAGE, the System Administrators Guild, Berkeley, CA, 1998.

[38] According to Stephen Johnson, the USENIX representative on the study group. USENIX pays close attention to the work of systems administrators.

ing on the list were desktop publishing specialists (ranked 8th), data processing equipment repairers (ranked 15th), and engineering, science, and computer system managers (ranked 23rd). These numbers are not collected data as are the other federal data we have considered in this section, but are only forecasts. Thus they concern the future, not the current situation. Why should they be considered as any kind of an indicator of the current situation? The reason is that the projections are based in part on the current situation, as well as on anticipated future changes that will affect supply and demand. It is unlikely that the projections for future years, especially in the near future, would have shown such a large predicted growth if there were not a current robust demand. It should also be remembered, however, that these kinds of projections are notoriously difficult to make and that BLS projections have sometimes been way off the mark.[39] For all of these reasons, these worker projections are probably the least reliable of all the federal data indicators of a shortage or tightness.

3. **Limited-scope studies.** Two studies are considered here. Both focus on software workers, which is the area of IT work with the greatest occupational growth. One study is national, the other regional. The national study was produced by the National Software Alliance, a consortium of industry, government, and academic leaders that was formed specifically to address their concerns that there is an IT worker shortage.[40] The study gives many different kinds of evidence, some based on federal data, many based on private data. We did not evaluate the methodologies used in the collection and analysis of these private data sources, but presumably there is a range of quality and reliability across these sources. What is perhaps most remarkable about the National Software Alliance's study, however, is the large number of different statistical analyses, from various sources, that support one another in showing the existence of a shortage, or at least a tight labor market, for software workers. Here are a few examples from the report based on private data:

- The Olsten Corp., a large staffing services company, conducts an annual staffing survey of a range of North American businesses. The 1997 survey indicated that the high-

[39] For example, in 1984 BLS projected 520,000 computer science and systems analysts jobs in 1995, but there were actually 860,000. BLS predicted a 53-percent growth in electrical engineering jobs over this period, whereas there was actually a 9-percent decline. (See John H. Bishop's commentary in the Levy Symposium Proceedings, p. 8.)

[40] National Software Alliance, "Software Workers for the New Millennium: Global Competitiveness Hangs in the Balance," Arlington, VA, 1998. This Alliance has a Department of Defense orientation. It has been argued that salaries and benefit packages offered to IT workers in the defense industry are relatively poor compared with those offered to IT workers in other sectors; and that this disparity creates a difficult recruiting and retention situation that is reflected in the National Software Alliance's view that an IT worker shortage exists, and the need to act on it for national security reasons (Michael Teitelbaum, Sloan Foundation, personal communication, March 1999). Whether one needs to question the reliability of the National Software Alliance's data, even if they are an interested party, is unclear.

tech sector had a much higher percentage (59%) of companies reporting that they did not have enough employees to meet their operational needs than any other for-profit sector. [41]

◆ Microsoft Corp. had more than twice as many job openings in its Microsoft Certified Solution Provider program in the United States than there were software workers in all of Ireland—the country that exports the world's second largest amount of software after the United States (and, hence, presumably one of the leading potential sources of IT workers for the United States).[42]

◆ The National Software Alliance analyzed twenty-one private salary surveys, all of which showed that IT worker salaries were rising faster than inflation. A study by the Deloitte and Touche Consulting Group indicated an increase of 7.45 percent from 1996 to 1997 for computer networking professionals. *Computerworld's* 1997 salary survey revealed average annual salary increases of more than 10 percent in 42 percent of the twenty-six occupations tracked.[43]

◆ Starting salaries for computer engineers with a new bachelor's degree increased by 5.8 percent to $39,722 from 1996 to 1997.[44] (This increase is well above the national inflation rate, but lower than increases in a few other professional occupations.)

◆ The insurance, automotive, computer software and hardware, telecommunications, and pharmaceutical industries all have annual turnover rates of between 15 percent and 19 percent for software workers.[45]

The second study, conducted by the Washington Software Alliance, looks at software workers in the State of Washington. [46] As the Alliance itself notes, the situation in Washington is not entirely representative of the nation as a whole. The average software wage in the state is reported to be $66,752, the highest of any state in the nation. They also note that growth in the software industry in the state is outpacing the national average, with a growth from 1990 to 1996 of 17.8 percent compared with a national growth of 9.8 percent. The state has two major employers, Microsoft and Boeing, that may make its situation somewhat different from the nation as a whole. Given these caveats, it is useful to consider the report's statistics, which suggest a serious worker shortage.

The Alliance's survey includes all positions in the Washington State

[41] "1997 Olsten Forum on Human Resource Issues and Trends: Staffing Strategies," William Olsten Center for Workforce Strategies, Melville, NJ, 1997.

[42] "Ireland: The Software Capital of Europe," National Software Directorate, Forbairt, 1997; Christina Torode, "Closing the IT Skills Gap," *Computer Reseller News*, December 1, 1997, Issue 766.

[43] See National Software Alliance, op. cit., page 2-21 for citations to the original studies.

[44] Based on data from the National Association of Colleges and Employers, "Salary Survey," July 1997.

[45] Based on 11th Annual Salary Survey, *Computerworld*, September 1, 1997.

[46] See http://www.wsa1.org/gotwork/wasoft.htm

software industry, technical and non-technical. The industry includes 2,500 companies, with $20 billion in annual revenue and 47,000 employees. There are 7,300 current vacancies (15.5% of all positions), with 64,000 total desired hires in the next three to four years. A $12.8 billion three-year revenue gain is projected if these positions can be filled. Three-quarters of all jobs require a bachelor's degree or higher. The greatest need (largest number, hardest to hire, driving force for the industry) is for junior and senior developers—positions that require a BS or MS in computer science or computer engineering. There are eight jobs for every relevant in-state bachelor's graduate, and four jobs for every relevant in-state associate's (two-year) degree graduate. Unlike the views of a number of other industry representatives, the Washington State software employers are very satisfied with the technical, social, and English-language skills of those they hire. Their problem, they claim, is a numbers gap, not an educational quality gap.

In addition to considering how representative the Washington State situation is of the national scene, determining what the statistics actually mean also needs to be addressed. It is difficult to project accurately the number of new positions that will exist or be needed in the future, or the dollar value added by additional filled positions. While Microsoft and Boeing may hire many of their workers from in-state schools, they both recruit nationally, making it somewhat misleading to calculate state-graduate-to-open-job ratios. The problems of using vacancies as an indicator were described earlier.

4. **Methodologically challenged national studies.** The first ITAA report initiated the national debate over the IT worker shortage. This section will consider it and its follow-up report.[47] Criticisms concerning the ITAA's methodology and results were discussed earlier, but are briefly reviewed here.

The main criticism was the direct count of supply and demand that ITAA tried to make. The first study used undergraduate graduation rates in computer science to measure supply, when this is only one of many supply sources of IT workers. The report also did not present available data that indicated the number of undergraduate majors in computer science was increasing after a long decline. On the demand side, a very broad definition of an IT worker was used, and the telephone survey used to collect the data had a very low response rate. Because of the low response rates, the results are statistically questionable. For example, companies that needed IT workers may have been more willing to respond to the survey than companies that did not. For these reasons, there are real questions about the reliability of the predictions in the two ITAA reports, respectively, that there are 190,000 and 346,000 unfilled IT positions in the United States. But even if the results do not have the weight of scientific evidence, they

[47] "Help Wanted: The IT Workforce Gap at the Dawn of a New Century," Information Technology Association of America, Arlington, VA, 1997; "Help Wanted 1998: A Call for Collaborative Action for the New Millennium," Information Technology Association of America and Virginia Polytechnic Institute and State University, March 1998.

suggest that a number of companies are having difficulty filling positions.

Other kinds of evidence are also cited in the first ITAA study to support a worker shortage. Here are some samples:

◆ 82 percent of the companies that responded to the ITAA survey indicated that they planned to increase the number of IT workers they employed in the coming year, while only 2 percent indicated they planned to decrease the number.

◆ 83 percent of the companies indicated that they thought the demand for IT workers was higher than the demand for other kinds of workers.

◆ William M. Mercer, which conducts a compensation study for ITAA, noted an increase in average hourly compensation of nearly 20 percent from 1995 to 1996 for operating system software architects and consultants, about five times the national average.

The second ITAA report, in addition to its information about vacancies, provides a combination of anecdotal information and statistical data from other sources. All of this additional evidence they cited suggested a shortage/tightness. (However, it should be remembered that ITAA is an advocacy group and that they presumably chose only examples that supported their position.) Here are some of the examples ITAA cites:

◆ The high IT vacancy rates of two companies are noted: 14 percent at Booz-Allen & Hamilton Inc., and 16 percent at Mary Kay Inc.

◆ A quarter of the IT managers reported that employees who departed voluntarily in the previous year was in excess of 10 percent of their organization's total programming staff, according to an *InformationWeek* survey.[48]

◆ Some companies were paying employees up to $15,000 for referrals that led to critical IT hires; company stock options were reported as being routinely offered; benefits and amenities such as gyms and exercise facilities, day care, restaurants, medical assistance, flexible work schedules, and increased vacation time were increasingly common.[49] (But the report did not reveal how often these perks and benefits were offered.)

5. Anecdotal evidence about employer actions. Table 4-4 provides a list taken from the Barnow, Trutko, and Lerman paper on what a company might do in reaction to a labor shortage. There is anecdotal evidence that every one of these strategies has been adopted in connection with IT workers.

◆ *Recruiting*. There are many signs of increased recruiting. More

[48] E. Cone, "Staffing: Short Supply," *InformationWeek*, November 1997 (http://www.techweb.cmp.com/iw)

[49] "Good Help Is Hard to Find," *Computerworld,* October 1997, and "Good Help Is Hard to Find," *Computerworld,* November 1997—both at http://www.computerworld.com; "Tech Corporate Culture Cozy, Creative," *USA Today*, November 1997 (http://www.usatoday.com); E. Cone, "Staffing: Short Supply," *InformationWeek*, November 1997 (http://www.techweb.cmp.com/iw).

Table 4-4

Company Reactions to a Worker Shortage

◆ Increase recruiting efforts ◆ Increase use of overtime ◆ Reduce minimum qualifications for the job ◆ Restructure work to use current or new employees in other occupations	◆ Substitute machinery and equipment for labor ◆ Train workers for the jobs ◆ Improve working conditions ◆ Offer bonuses to new employees ◆ Improve wages and fringe benefits ◆ Contract out the work ◆ Turn down work

Source: Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," submitted by the The Urban Institute to the Office of the Assistant Secretary for Policy, U.S. Department of Labor, draft final report, February 25, 1998, pp. 22-31.

ads are being placed in both the traditional print sources and on the Internet; and display ads, which attract more attention and are more expensive, are on the rise. Recruiting on campus appears to be way up. Georgia Tech, for example, has seen the number of employers attending their IT career days double each year for three years, until meeting space capacity was reached. Job fairs are being held with increasing frequency, if ads in the local and national newspapers are any indication. Booklets listing available IT jobs have started to be distributed free of charge in video stores and other retail establishments throughout Northern Virginia, next to the Apartments to Rent booklets. It is apparently becoming more common for companies to pay significant recruitment bonuses to current employees who can recruit new workers. Companies are also increasingly targeting specific schools in their recruitment efforts, and are sending their corporate executives and highest profile researchers to these campuses to raise the company's visibility with the students.

◆ *Overtime.* There have been some reports of extra overtime for IT workers. IT faculty and IT managers in industry are typically exempt employees who work long hours without extra compensation. IT workers in computer startup firms may also work long hours without extra compensation because there is the expectation of total dedication in return for a cut of the action. But overtime is generally paid to IT workers by most companies outside the IT sector, and by many of the larger and more established computer and software manufacturers. Because of the prevalence of long hours, employers have implemented a number of standard practices, such as feeding employees who work late or taking the development team on expensive vacations after a project has been successfully completed. However, hours can only be increased so much and for so long before the strategy becomes counterproductive, leading to poor morale and shoddy workmanship, for example.

◆ *Reducing minimum qualifications*. There is a long history of companies hiring people for IT jobs who possess fewer or different skills from those outlined in the job description. Perhaps this is because the unemployment rate for IT workers has been so low for such a long time. There is some evidence that today companies are recruiting in more places, and hiring students graduating from schools that are less prestigious than they would have considered in the past. As discussed elsewhere, hiring underskilled employees can be a dangerous practice because productivity and quality levels vary highly from worker to worker in many IT occupations, especially ones involving programming.

◆ *Restructuring work.* IT work is being restructured so that human substitution can occur. Clerical staff are being trained to work as local area network or database administrators, Web designers, and software installation experts. Companies are trading off a greater amount of general and foundational education (such as would be gained from a bachelor's degree and some course work in computing) for training in a specific, current technology (high school graduates with a six-month certificate program to become a Novell or Microsoft technician). In some cases, companies contract out the technical aspects of the work and retain only a small IT staff of one or two leaders and some maintainers.

◆ *Substitution of machinery for labor*. There have been many efforts to substitute machinery for labor, but the long-term effect is unknown. Companies relying on software applications are rapidly introducing automated software maintenance programs that replace workers, but, in many programming environments, technology is expected to reduce labor by no more than ten percent.

◆ *Training*. Companies seem to be more willing to retrain current employees than to train new workers. In a highly competitive marketplace with narrow windows of opportunity to introduce a new product, such as an Internet-based product, it is not surprising that companies would be reluctant to hire workers who needed six months before they could be fully productive. However, some companies, such as Andersen Consulting and PeopleSoft, have a successful practice of hiring bright college graduates, independent of their undergraduate major, and giving them intensive technical training when they join the company. It is unlikely, however, that this practice would work for all companies.

◆ *Working conditions*. Companies in the IT industry have a long-standing record of providing whatever is needed in the way of benefits, improved offices, child care, flexible working hours, and other non-wage perquisites to attract and retain workers. It is somewhat harder for companies in some other industrial sectors to give preferential treatment of this kind to their IT workers and not to their other workers.

◆ *Bonuses*. Sign-on bonuses are becoming increasingly common for IT workers.

◆ *Wages and Benefits*. This issue was discussed earlier. Anecdotal evidence suggests that IT workers are sensitive to market salaries and benefits and are willing to switch jobs on this account. Organizations that have restrictions on their ability to meet market conditions, such as some colleges and government organizations, often have trouble attracting or retaining IT workers.

◆ *Contracting.* The amount of IT work that is contracted out is already substantial and is growing. The rapid growth of IT consulting firms is evidence of this trend.

◆ *Refusing work.* It is common for IT departments to tell their internal customers that they cannot meet their requests. It is difficult to determine how much external work is refused.

6. **Qualitative evidence.** There is also an abundance of non-statistical evidence. This does not have the same persuasive force as methodologically sound quantitative data because it is hard to distinguish the special case from the general rule, but qualitative evidence can be both revealing and suggestive—especially if there is a lot of it, of various kinds, and from various sources. The preponderance of this anecdotal information supports either a shortage or a tightness in the IT labor market, although none of the evidence available can distinguish between the two. The third bullet below presents one of the few examples that speak against there being either a shortage or a tightness.[50] Here are a few examples:

◆ Every company our study group heard about, both in the IT sector and in other sectors, claimed it was experiencing difficulty with IT recruitment (either worse-than-expected results in hiring, or having to work much harder than in the past to achieve hiring quotas).

◆ The study group came across various professional societies, state government agencies, regional economic trade associations, private foundations, individual colleges and universities, university systems, and chambers of commerce that were concerned about and studying the IT labor shortage issue, or that had developed programs to develop IT workers.[51] Most of these organizations would not have devoted the time or effort unless they were convinced there was a problem.

◆ A small body of non-statistical evidence speaks against a worker shortage (or even tightness in the market). This includes anecdotal evidence from older technical workers unable to obtain IT jobs, for example in the electrical

[50] For some examples of articles questioning the existence of a shortage, see Margie Wylie, "The Skills Shortage That Isn't," CNET news.com, February 4, 1998 (http://www.news.com); also Dominique S. Black, "Taking Shots at the Labor Shortage," *IT Careers,* March 23, 1998.

[51] For example, the Society for Information Management (SIM), a professional association of 2,700 managers of information technology and its applications to business, has drafted a position paper on the worker shortage. "SIM believes this labor shortage is the most severe in the 50-year history of computing, and will continue well into the next millennium…[in part because of] a fundamental shift in investment economics favoring increased use of IT." ("Addressing the Information Technology Workforce Shortage," Position Statement, Society for Information Management, October 1998, Chicago, IL.) A Web site maintained by the Department of Commerce profiles 170 IT worker-development programs throughout the country. See http://www.ta.doc.gov/go4it/

engineering field. One would assume that experienced electrical engineers would have some computer skills, mathematics, science and engineering background, problem-solving and communications skills, and a knowledge of industry that would make them desirable to companies needing IT workers; but electrical engineers indicate some trouble being hired for these IT jobs.

Conclusions:

- There is no way to directly answer the question of whether there is a shortage of IT workers because there are no adequate definitions or adequate data to directly count either supply or demand.

- Other sources of information are inferential and less reliable than the direct counting approach. Indeed, there are credible reasons for doubting virtually any piece of evidence that is currently available.

- The inferential evidence does not easily allow one to distinguish between a shortage and a tightness in the IT labor market. (The indicators would look about the same whether there was a shortage or simply tightness.)

- The statistical indicators based on federal data, the regional and occupation-specific data studies, the methodologically challenged advocacy studies, and the qualitative evidence almost all suggest either a tightness or a shortage.

- It is likely that there are spot shortages, both in specific geographic regions and in specific occupations. In a field experiencing rapid growth and rapid technological change, it would be surprising if there were not such shortages.

- Discussion of supply and demand of IT workers would be more insightful and useful if the market could be segmented by geography and/or occupation, but data do not exist to carry out this analysis.

Where Are IT Shortages Occurring?

There is only anecdotal evidence to answer this question. The federal data categories are too coarse and the data too old to be of much help. The software area appears to be experiencing significant shortages at this time, especially for applications relating to networking, databases, and Internet-based applications. These shortages tend to be concentrated in niches and in jobs requiring higher skill sets. The problem is worsened by the fact that software workers are not always qualified to move from one software job to another. A programmer experienced in one programming language may not be effective in another. It is not simply a matter of learning the grammar and vocabulary of the language. More critical is learning the underlying methodology used with that programming language to attack programming projects, and this methodology varies considerably across programming languages. For example, programming in COBOL is very different from programming in Java; and it has been hard to retrain COBOL programmers (who received their experience on mainframe computers and are briefly in demand today because of the Y2K problem) to be Java programmers (who are likely to be in great demand well into the new millennium to program applications for use on the Internet).

Based on anecdotal evidence only, the following points represent the study group's consensus about occupations where either demand outstrips supply or many positions are filled with underskilled workers:

- programmers, but especially those who are familiar with Oracle, SAP, BAAN, and ERP;

- programmers and designers with object-oriented and Java experience;

- Web and e-commerce specialists;

- Network designers;

- Problem-solvers with enough IT background to be able to work as consultants for the major accounting and consulting firms (Ernst & Young, Andersen Consulting, PriceWaterhouseCoopers, EDS);

- Faculty, especially in high schools and some two- and four-year colleges;[52] and

- Managers and project leaders.

[52] A small survey on faculty hiring carried out by the ACM Special Interest Group on Computer Science Education, to which 64 institutions responded, suggests that faculty recruitment is more difficult in non-research institutions. When asked how difficult or easy faculty recruitment is, the survey received the following responses: at schools that grant the Ph.D. in computer science: easy 12.5%, moderate 31.3%, difficult 56.2%; at schools that grant the master's degree as their highest degree in computer science: easy 4.7%, moderate 28.6%, difficult 66.7%; for schools that grant the bachelor's degree in computer science as the highest degree; easy 3.7%, moderate 3.7%, difficult 92.6%. Preliminary results, July 27, 1998. For more information, contact Professor Paul Myers, Department of Computer Science, Trinity University, San Antonio, TX.

Chapter 5. Supply—The Degree Programs

What Are the Sources of IT Workers?

The traditional, formal educational system remains critically important to the training of the information technology (IT) workforce. Different kinds of jobs within the IT field require very different skill sets and levels of knowledge, and thus different IT jobs vary greatly in the kind and level of education they require. Formal programs leading to associate's, bachelor's, master's, and doctoral degrees in IT-related fields all have their place in the supply system. An associate degree will train a person for certain kinds of entry-level positions that may involve maintaining or tending information technologies, whereas a doctorate might prepare a person to create new information technology. None of these relations between training and particular IT occupations are hard and fast, however.

The associate's and master's degree programs are important supply sources for IT workers because they tend to be more vocationally oriented than bachelor's or doctoral programs. However, the bachelor's degree programs produce the largest number of graduates for the IT workforce, and the doctoral programs are critical in the production of trained workers for both the occupations involving conceptualization and advanced development, and for faculty positions that will educate the next generation of IT workers. The most popular IT-related majors are computer science, followed by computer engineering and management information systems. However, one author has recently identified twenty IT-related degree disciplines offered in the United States (see table 2-1 in chapter 2), and new ones are being created all the time.[53] What these programs teach is more important than what they are called. Indeed, program names are often confusing, and it can be difficult to establish similari-

[53] See Peter J. Denning, "Computing the Profession," *Educom Review*, November 1998; also Denning, "Information Technology: Developing the Profession," unpublished discussion document, George Mason University, December 4, 1998.

ties or differences between programs solely on the basis of their names.

One of the least known and most important facts is that the vast majority of IT workers do not obtain formal degrees in IT-related disciplines. Perhaps the most common of the many different training paths to an IT career is a bachelor's degree in some technical field unrelated to information technology, accompanied by some course work in either an IT subject or in closely related preparatory fields such as mathematics, electrical engineering, or business.

At the same time, certain IT occupations do demand a particular kind of formal education. Advanced researchers, such as faculty members in research universities or principal scientists in industrial research laboratories, almost always have a doctorate in an IT-related discipline, usually computer science or computer engineering (or occasionally in a closely related field such as physics, mathematics, or electrical engineering).

Over the past decade, there have been vast changes in the characteristics of IT work and preparation for it. Traditionally, higher education served as the basis for one's career, although some of the larger IT companies had training programs for their employees. Today, higher education is an entry ramp into a job, but it is not expected to carry one through a career. Taking advantage of on-the-job experience and various kinds of continuing education, the IT employee is today expected to engage in a life-long retraining effort, which is intended to keep the worker up to date in this rapidly changing field.

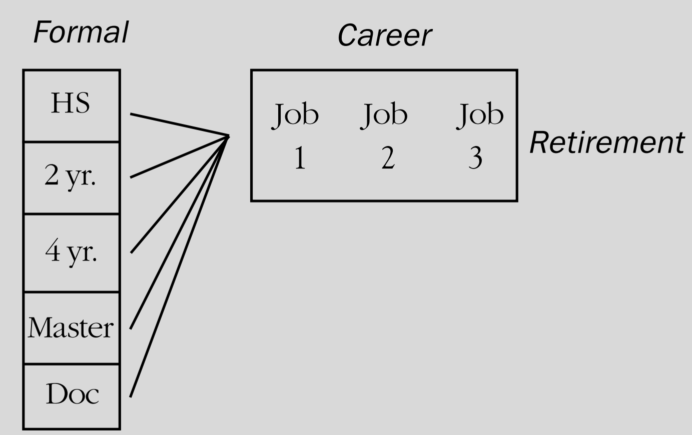
Many different groups supply this continuing education. The higher educational system has a major role, offering seminars, short courses, and groups of courses that lead to certificates in specialized aspects of information technology such as network administration or biocomputing. Universities often attract the mid-career employee who goes back to earn an additional degree—perhaps a computer science degree for someone who majored in humanities or a master's degree in business administration for the computer engineer. Every level of the higher education system participates, but the training is most likely to come at the associate or master's level.

Others provide continuing education and retraining as well. For-profit educational companies, such as DeVry or the University of Phoenix, offer formal degree programs and certificate programs. Private consultants and private training companies offer specialized seminars, as well as customized training programs for individual companies. Companies themselves are getting in to the training business for their own employees (and sometimes for others), forming so-called "corporate universities" that they may develop on their own or in partnership with one of the other traditional or for-profit suppliers. These corporate universities teach not only IT technical materials, but also develop communications and interpersonal skills, and impart knowledge of business and industry practices.

The need for continuous retraining has made it necessary to rethink the way in which education is delivered. It has to be made available at a time, place, and in a

Figure 5-1

IT Worker Traditional Career Path



Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

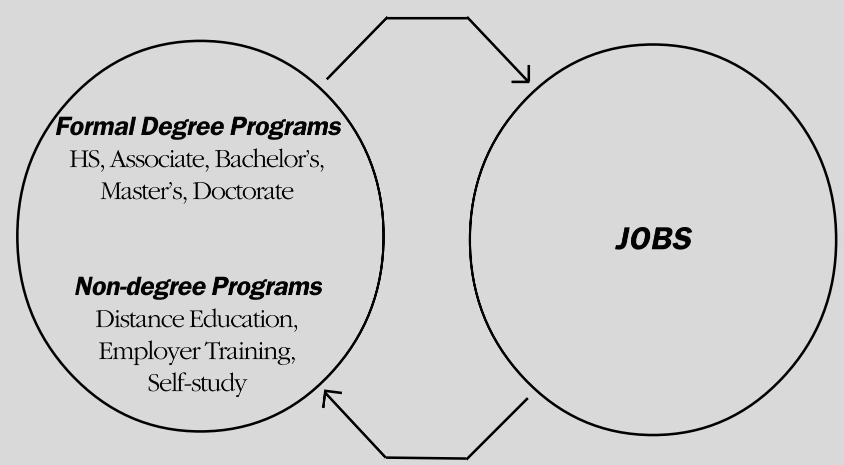
style that accommodates the employees' work and personal lives. This requires more frequent offerings on evenings and weekends, scattered around many different geographical locations. Even better, in some cases, is the use of teaching methods that free the student from a specific time and place. Computer, Internet, and broadcast technologies are being used to develop various kinds of distance learning, some of which can be engaged by the student asynchronously—that is, when the student wants the training, not when a teacher is scheduled to give a lecture. These technologies are available in a rudimentary form today, but they continue to be developed and are being put into practice at a rapid pace.

How Have Career Paths for IT Workers Changed Over Time?

Information technology workers are pursuing a training and career path today that is different from that practiced by most members of this profession as recently as a decade ago. The traditional career path can be represented by a linear model, as shown in figure 5-1. The prospective IT worker prepares for the workforce through formal (nonprofit) education, gets a job, and moves up through the worker and management ranks—working for one or a very small number of employers until retirement. There are various exit points in the formal educational system, represented by the awarding of a degree—the high

Figure 5-2

Current IT Worker Career Path



Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

school diploma, associate's degree, bachelor's degree, master's degree, or doctorate. The place at which one exits the formal educational system largely determines the starting point in the workforce, and it also restricts the range of career opportunities. It is uncommon, for example, for a person to rise to senior management without holding at least a bachelor's degree, notwithstanding the many journalistic accounts of high school and college dropouts becoming millionaires in the computer industry.

The current career model, as represented by figure 5-2, is more complicated and less linear. There are multiple opportunities for education and training: various levels of school-based formal degree programs (as before), non-degree programs produced by these same suppliers, distance education programs, employer-based and for-profit training organizations, and self-study. Unlike the traditional career path, where one's education was completed before entering the workforce, the current model has workers moving back and forth between the educational system and the workforce, or participating in them concurrently, as they continuously, or at least periodically, retrain throughout their careers.

In this new model, significant linearity remains in the college and university degree programs. For example, a bachelor's degree is expected before entering into a doctoral program. But when workers seek additional training, even from the traditional college and university system, there is no most common path. IT workers with a bachelor's degree, for example, might enroll in: 1) a community college for a certification program in networking technology; 2) a four-year college to take mathematics or science courses to bolster their basic knowledge; 3) a few courses or a degree program at the master's level in information systems or business; or 4) a doctoral program in computer science. The purpose of this formal training might be to help them to do their current job better, or perhaps to prepare them for a better job. However, there are many paths to a particular IT career. Box 5-1 presents six examples of non-traditional career paths of IT workers. All of the people in these examples are personally known to members of the study group.

Company training is, of course, not a new phenomenon. For many years, companies have been providing some training to their employees. A few large companies, such as IBM, AT&T, and Motorola, have long placed an emphasis on this kind of training. However, as the discussion below on corporate universities indicates, there has been a very pronounced increase over the past decade in both the amount of training and the expectation that all employees (rather than a few select groups of employees) will engage in continuous or periodic retraining.

The attitude of employees toward jobs and employers has changed as well. Given that lifetime employment with a single employer is increasingly rare, workers no longer regard the particular job they hold as a rung on a ladder they are climbing within the company. They are less likely to accept just any job the company management wants to assign. Jobs are now regarded as another element of the training process, of learning by doing, and employees move from job to job to gain new skill sets and experiences rather than assume they will stay with a particular company for life. Acquiring new skills allows them to move within the entire IT work community for opportunities, rather than solely within a particular company.

The following sections describe formal degree programs, followed in chapter 6 by other forms of training. Although the description of the non-formal methods of training is briefer and the statistics more meager, this form of training appears increasingly to be prevalent and a principal means of obtaining many IT skills.

What Is the Role of High Schools in the Supply System?

It is during the high school years that people typically receive their first knowledge and skill sets in information technology. Some of this learning occurs in formal programs in the schools, but for many students it is likely that even more learning occurs through personal exploration and interaction with peers. As personal computers become more common in homes and schools, students are gaining exposure at progressively earlier ages; and this will no doubt lead to progressively earlier introduction of computers into the curriculum. While it is undoubtedly valuable to find ways to enhance informal learning, this discussion focuses on formal programs in the high schools—both vocational programs that prepare the student directly to

Box 5-1

Non-traditional Paths to and from IT Careers

AAA is a 56-year-old Ph.D. in Astronomy. He worked for nearly twenty years in a number of large and small companies, the last ten years in the Aerospace industry. When that industry downsized in the early '90s, he was laid off. Living off savings, his wife's salary, and his severance package, he returned to school full time and earned a master's degree in Computer Science. He quickly found work with a semiconductor company.

BBB is a 25-year-old college graduate who majored in Psychology, and worked in a daycare center after graduation. As a result of both home and college environments, she had basic computer literacy, and, discouraged by the low salaries in childcare, took a temporary job in IT doing quality assurance. She enjoyed this work, and now works full time doing quality assurance for a company involved in Internet commerce.

CCC is a 38-year-old with a master's degree in Russian economic history. While working on his masters, his roommate got a PC, and CCC became intrigued with it. He started reading books on computing. He landed a job with a company that made systems software, and ended up moving to a job where he is one of the major software resources of a small company.

DDD was a poetry major in college, working on her master's. She took a summer job at a bank as a technical writer when the bank was just introducing ATM machines. She became interested in the technology, dropped out of school, and ended up working for five years with the bank, by the end of which she was doing software project management. She joined a start-up company that eventually became a major producer of computers, and ran their software delivery system for many years.

EEE was a COBOL programmer for a major automaker. His department had more than 200 workers in his division. After a successful pilot project the company decided to move to Java and object-oriented programming. They used a rapid re-skilling program designed by one of the largest IT consulting companies. About forty co-workers passed the certification tests and are working on other projects. EEE is working at the local McDonald's. The company is busy recruiting new college hires and experienced object programmers to fill the void.

FFF was married at 18 to a Navy man, who left her with two small children and only a high-school education. She got work at a bookbindery. After several years learning the printing business she made the jump to electronic publishing, joining a start-up company in this field. Being willing to "tackle anything," she rose in management until she was assistant to the President and Chairman.

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

enter the workforce, and academic programs that prepare the student for college study.

High school vocational programs train students for many different occupations, but only a few of them, such as data entry and electronics technician, are IT occupations.[54] The horizons are limited for people who enter the IT workforce by this route, unless they are willing to seek additional education over time. This is true even of the bright high school students reported in the national press who have been hired before completing high school to be Web designers or other kinds of programmers.[55] Unfortunately, many students who enter the vocational high school tracks will not have the foundational skills for further education and career advancement. A few model programs scattered around the country have tried to address this issue. These programs blend academic rigor with vocational objectives. Students are attracted to the programs because they are guaranteed jobs upon graduation. The programs generally have a local focus, with the high schools partnering with industry and two- and four-year colleges and universities in their region. While not all students from these programs actually attend college, the educational requirements are consistent with the university-bound curriculum. This enables the participant to better handle a first job and to more easily pursue further education later.

Anecdotal evidence suggests there are several challenges for the high schools in preparing even college-bound students for IT careers. Because many parents know less about the computing professions than the more established professions, it is incumbent on high school guidance counselors to provide information about computing careers. Counselors themselves need to know much more about the career opportunities and the training needed to enter these professions. Because of the rapid growth of information technology, high schools are having difficulty attracting qualified teachers and helping them to keep their academic preparation current. There are also particular problems of attracting female and minority students to IT careers (see chapter 7.)

Two kinds of programs appear to be succeeding in preparing high school students for IT careers. One is directed primarily at students who are already on the academic track. It offers college-level courses in computing (sometimes conferring college credit), taught by high school teachers or faculty from local colleges. The second type of program tries to make technical (but not necessarily IT) careers attractive to able students who might not otherwise enter college and get professional jobs. It is designed for at-risk students who are more likely to be minorities or come from poor communities. An example is the Engineering Vanguard Program of the National Action Council for Minorities in Engineering, Inc. (NACME). This program conducts

[54] One example of an IT program for high schools and two-year colleges is the Cisco Network Academy. See http://www.cisco.com/edu/academies/index.html

[55] See, for example, Ethan Bronner, "Computer Industry Luring Students Into Dropping Out," *The New York Times,* June 25, 1998.

its own assessment of high school seniors (rather than relying on school grades and evaluations), provides intensive academic enrichment, and sends students to participating colleges on full scholarships. The NACME program has shown excellent retention rates.

Table 5-1

Two-year Colleges Awarding Computer and Information Science Degrees

Year	Number of Institutions
1989-1990	632
1990-1991	625
1991-1992	696
1992-1993	697
1993-1994	709
1994-1995	727

Source: National Center for Education Statistics, *Digest of Education Statistics*, using preliminary data for 1990-91 and final data for all other years.

What Is the Role of Two-Year College Programs in the Supply System?

Both of the major degree tracks (transfer and non-transfer) in two-year colleges are a source of IT workers. Many students enroll in transfer programs, where the objective is to prepare students to transfer to a four-year school to complete a bachelor's degree upon completion of their two-year associate's degree. The education and training they receive, which is roughly an equal mix of general education and discipline-specific courses, is similar in depth and breadth to what students would receive in the first two years at many four-year colleges. This alternate route to a bachelor's degree is important for students who have financial or geographic restrictions, such as needing to live at home, or who do not have confidence in their academic abilities at the time of high school graduation. Thus the transfer programs are the beginning of one educational path for higher-level IT occupations.

Also popular are non-transfer programs, which are designed to prepare graduates for immediate employment. These programs tend to have a high concentration of discipline-specific courses—generally 75 percent—combined with general education courses. Non-transfer programs prepare students for various kinds of IT work, such as network installation, Web development, or computer support services. The knowledge and skill sets acquired tend to focus more on a specific subarea of computing, such as Web development, and less on the general theory and concepts that are emphasized in a bachelor's degree program. Compared with those holding bachelor's degrees, therefore, these students tend to be better prepared to immediately begin performing a job in the specific subarea in which they have been trained; but they are less well prepared to use their skill and knowledge base to transfer to other kinds of IT work.

Table 5-1 shows the number of two-year colleges awarding degrees in computer or information systems. The number increased by about fifteen percent during the first half of the 1990s. Assuming

Table 5-2

Associate Degree Production in Information Technology	
Year	**Number of Degrees Awarded**
1992-1993	9,196
1993-1994	9,301
1994-1995	9,152

Source: National Center for Education Statistics, *Digest of Education Statistics*

the increase continued at approximately the same pace during the second half of the decade, the number of two-year colleges awarding IT degrees numbers between 800 and 850 today. In 1994-95 there were 2,184 two-year colleges in the United States.[56] Thus in that year only about one-third of the nation's two-year colleges offered programs in information technology. This suggests there are significant growth opportunities in this part of the supply system.

There are no reliable statistics on enrollments in IT courses at the two-year college level.[57] Somewhat better data are available for associate degrees awarded in information technology. Table 5-2 shows that there were between 9,000 and 10,000 degrees awarded in each of three years during the mid-1990s. These numbers include all degrees awarded in the areas of computer and information sciences, computer programming, data-processing technology, information science and systems, and computer systems analysis. These statistics underreport, at least slightly, the number of IT workers being trained in the two-year colleges, in that students also prepare for IT careers in several other majors that graduate a mixture of IT and non-IT workers. Two examples are electronics and graphic arts programs. Electronics programs are diminishing nationwide, due to lack of students. Graphics arts programs, however, are on the rise because of the interest in computer graphics and Web design. It is hard to estimate the exact number of associate degrees awarded in IT areas in the mid-1990s, much less today, but the number appears to be on the order of 10,000 per year.

Two occupations, electronics technicians and Web designers, illustrate some of the dynamics that are occurring in the industry that have a bearing on the kind of training needed. Many of the routine tasks that electronics technicians graduating from associate degree or high school vocational programs used to do are now done by machine rather than by a technician. As a result, the skill set in the technician's job is changing, requiring the technician to think more abstractly, have a greater basic

[56] U.S. Department of Education, National Center for Education Statistics, *Digest of Education Statistics*.

[57] The only relevant data found were from the National Center for Education Statistics, as reported in the *Digest of Education Statistics*. These statistics showed a halving of enrollments from the 1992-93 academic year to the 1995-96 academic year, from 583,000 students enrolled to 275,000 enrolled. The data were extrapolated from samples that may have been too small to be meaningful, they combine associate degree enrollments with certificate program enrollments, and they differ greatly from the experiences of the two-year college personnel consulted for this report. For these reasons, there is little confidence in the reliability of these statistics.

knowledge of the technology, and work with more complex systems.

The situation with the job of Web designer is similar but more complicated. Several years ago, Web sites were rudimentary; nevertheless, significant programming ability was required to write the HTML code that is used to lay them out. Over the past several years, technology has been designed to automate many of the programming aspects of the layout. Thus if one is doing a simple Web design today, it is possible to use automated software that does not require programming skills—in fact, the task is similar to using word-processing software. However, Web pages have become much more elaborate and powerful, and high skill levels are still required to lay out pages that meet these new standards. Some of these skills involve programming, but others involve knowledge of design or human-computer interfaces. As these two examples illustrate, the training system has to be sensitive to these rapid changes in the required knowledge and skill sets of IT jobs in order to train useful workers.

A number of qualitative concerns about impediments to two-year college production of IT workers were expressed during the course of this study:

◆ Inadequate career counseling at the middle school and high school levels leaves students in two-year colleges ill prepared to make decisions about their degree programs.

◆ Weakness in the academic preparation of entering students has created a need for remedial education in basic mathematics, reading, and English. This process delays the production of graduates.

◆ The availability of jobs prior to graduation results in students not completing their degree requirements, which may have long-term negative impact on their ability to advance or change careers.

◆ Four-year colleges sometimes impose artificial barriers to the acceptance of transfer credit from two-year colleges.[58] These can result in the unnecessary repetition of course work or can dissuade students from matriculating in a bachelor's program.

◆ There are similar difficulties in transferring credits between the transfer and non-transfer tracks, even within the same two-year college. This can box in students who begin in a non-transfer program and decide subsequently that they want to pursue a bachelor's degree.

◆ Inadequate availability of trained faculty, good facilities, and other resources reduces the number of students who can be trained.

◆ Cultural attitudes learned in high school or earlier reduce pool of students electing to major in programs leading directly to IT employment. These factors particularly affect women and minorities.

[58] We understand there are also legitimate reasons, involving both quality and content, for not allowing transfer of credits from one school to another, or from one program to another.

What Is the Role of Four-Year College Programs in the Supply System?

Four-year colleges are the primary supply sources for IT workers. The first two years of the baccalaureate program typically offer general education and introductions to various disciplines. The final two years include substantial course work in a single major discipline. It is these final two years that is the principal focus of this section. In most cases, courses taken in the final two years enhance existing IT knowledge and skills, rather than providing first access to them.[59]

Three classes of undergraduate students tend to enter careers in information technology:

- Those majoring in a degree program focused specifically on some aspect of information technology (e.g., computer science, computer engineering, or information systems);
- Those majoring in a degree program in a closely related field (electrical engineering, mathematics); and
- Those who major in a discipline largely unrelated to information technology (psychology, management), but who take a cluster of IT-related courses as distribution requirements, electives, or a minor.[60]

[59]As this report was going to press, a monograph came to our attention on “change in the nature and extent of college students’ study of computer science over the period, 1972-1993, the occupational destinations of students with computer science backgrounds, and the forces that shape the path from higher education to the labor market.” (Executive Summary). There was not time to incorporate the findings of the monograph into this report, but the citation is provided for those interested in further examination of these issues: Clifford Adelman, “Leading, Concurrent, or Lagging? The Knowledge Content of Computer Science in Higher Education and the Labor Market,” Office of Educational Research and Improvement, U.S. Department of Education, May 1997.

[60] One might want to divide up this third category, and add a fourth category of students who major in disciplines far removed from information technology (e.g., English), but who get on-the-job training working as user support specialists in the university. Brian Hawkins, president of EDUCAUSE, described this class of IT workers to us: “On college and university campuses this process of internal training and development is the primary vehicle for finding user support specialists, IT support personnel in academic departments, etc. In universities, the internal consulting program, and the skills developed in course, as well as informal acquisition of skills are primary development vehicles, transforming English majors and other non-IT fields of study into quite capable support personnel. I would estimate that well over 2/3 of the young staffers in the user support arena who are hired in universities are humanists and social scientists. These young people developed appropriate skills in their 4 years, developed a liking for this work, and find the job opportunities better and higher paying. These individuals also have a better working knowledge of supporting other academic units, since they often bring their “educational training” to bear on their IT support functions. Many of these people have gone on to professional IT positions outside of the university, based upon their experience and OJT [on-the-job training]. None of these processes would show up in professional surveys as a way of preparing IT professionals.” Personal communication, March 8, 1999.

Box 2-1 (see chapter 2) shows the continuum of degree programs that focus on information technologies, as reported in a classification scheme developed by a National Research Council (NRC) committee in 1993. The objectives range from training students to develop hardware or software, maintain information systems in organizations, or provide information services. There is considerable overlap in these descriptions, and sharp boundaries cannot be easily drawn. Newly emerging computing areas, such as computer support services and Web designers, are not well covered by this classification; and colleges are not uniform in the way they name their programs. The description given for Information Science may better apply to programs in Library and Information Science. But the NRC classification remains a useful description of the kinds of IT programs offered by four-year colleges.

The professional societies and professional accreditation organizations provide guidelines on the skills and knowledge expected of graduates in several IT-related bachelor's degree programs. Model curricula for computer science and computer engineering are published jointly by the Association for Computing Machinery and the IEEE Computer Society, while model curricula for information systems are published jointly by the Association for Computing Machinery, the Association for Information Systems, and the Association of Information Technology Professionals.[61] Accreditation is provided for computer science by the Computing Sciences Accreditation Board and for computer engineering by the Accreditation Board for Engineering Technology (ABET).[62] Software engineering accreditation criteria were approved in October 1998 by ABET. Licensing of software engineers is currently being introduced into the United States by the State of Texas, where the state licensing board is working with the professional societies to develop standards and relevant examinations.

Although some data exist on the production of IT workers by four-year colleges, it has not been collected in a way that conforms to the NRC classification scheme. The National Science Foundation (NSF) is the primary source of data. Under its classification scheme, computing programs tend to be aggregated under computer science, computer and information sciences, or computer programming; while

[61] See, for example, "IS '97 Model Curriculum and Guidelines for Undergraduate Degree Programs in Information Systems," *The DATA BASE for Advances in Information Systems*, Vol. 28, No. 1, Winter 1997, ACM Special Interest Group on Management Information Systems (SIGMIS). The struggle to define an educational philosophy—much less a curriculum—in the field of information systems, which is beset by extreme interdisciplinarity and rampant technological change, is the topic of an editorial by Henry H. Emurian, "Information Systems: An Interdisciplinary Perspective," *Information Resources Management Journal*, Fall 1998, pp. 3-4.

[62] Virtually all of the departments in IT-related disciplines see the value of model curricula and pay attention to them, even if they do not adopt them as a whole. However, there is not universal adoption of accreditation. Many of the top-ranked computer science departments, for example, refuse to have their programs evaluated for accreditation because they believe the value derived is far outweighed by the difficulty of the accreditation process.

Table 5-3

Number of Four-year Colleges Offering Programs in Computer and Information Science 1989-1995

Year	Number of Institutions
1989-1990	1,059
1990-1991	1,042
1991-1992	1,036
1992-1993	1,039
1993-1994	1,042
1994-1995	1,068

Source: National Center for Education Statistics, *Digest of Education Statistics*, using preliminary data for 1990-1991 and final data for all other years.

computer engineering tends to be listed with electrical engineering in a way that is hard to disaggregate. Programs in business areas, such as information systems and management information systems, tend to be excluded.[63] However, the main computing programs in business can be captured reasonably well from the *Digest of Education Statistics*, which breaks out business information systems as a category of business degrees, and which has a subcategory for management information systems and data processing under the business information category.

Given these caveats about data, let us first consider the number of four-year colleges offering degrees in computer and information sciences. Table 5-3 shows that the number of schools offering four-year degrees in computer and information sciences was relatively constant at just over 1,000 throughout the first half of the 1990s. The total number of four-year degree-granting institutions in the United States was 1,855 in 1994-95.[64] However, some of these institutions specialize in a single discipline, such as theology, art, music, or design; and others may already be teaching computing as part of some other activity, such as mathematics. This same data set indicates that there were 1,145 schools granting bachelor's degrees in mathematics and 1,248 schools granting bachelor's degrees in English. Business management and administrative services was the major offered by the most schools—and this number was only 1,383. These facts suggest that the number of degree programs in computer and information science at four-year colleges could not be increased by more than 20 percent. Of course, the number of students graduated by each of these programs could possibly be increased, and it is probably more efficient to increase the size of programs than the number of programs.

Table 5-4 shows degree production in IT fields at four-year colleges. The largest number of degrees is given in computer science, followed by management information systems. It is hard to detect any trend from these figures. However, these data are old and do not reflect the dramatic recent

[63] See Joanna Fortuna and Rob Kling, "Information Systems Data Missing in Key Debates about the IT Worker Shortage: Data About the Education and Employment of Organizationally Insightful IT Workers," Working Paper, Center for Social Informatics, Indiana University, November 13, 1998.

[64] U.S. Department of Education, National Center for Education Statistics, *Digest of Education Statistics*.

Table 5-4

Number of Bachelors Degrees Awarded in Information Technology Fields 1992-1995				
Academic Year	Computer Science	Computer Engineering	Management Information Science and Data Processing	Other Business Information Systems
1992-1993	24,000	–	6,174	396
1993-1994	25,200	2,237	5,434	405
1994-1995	24,404	2,345	5,788	378

Source: National Center for Education Statistics, *Digest of Education Statistics.*

changes that seem to be occurring. The only data set that gives more recent data is the Taulbee Survey produced by Computing Research Association. The Taulbee surveys in fall 1996 and fall 1997 each collected data from more than eighty percent of the departments in the United States that grant doctoral degrees in computer science and computer engineering. These doctorate-granting departments represent approximately one-third of the national production of bachelor's degrees in computer science and computer engineering. The 1996 Taulbee survey showed an increase in students declaring majors in computer science of 40 percent over the previous year. The 1997 Taulbee survey showed an increase of 39 percent in declared majors over 1996. Thus, compounding the changes over the past two years, the number of students declaring majors in computer science and engineering effectively doubled (1.40 x 1.39 = 1.946). These figures may roughly hold true for all schools granting four-year degrees, not only for those that also grant doctorates in computer science and computer engineering. Of course, it takes several years from the time a student declares the major until graduation, but presumably there will eventually be comparable percentage increases in the number of students graduating with four-year degrees in computing.

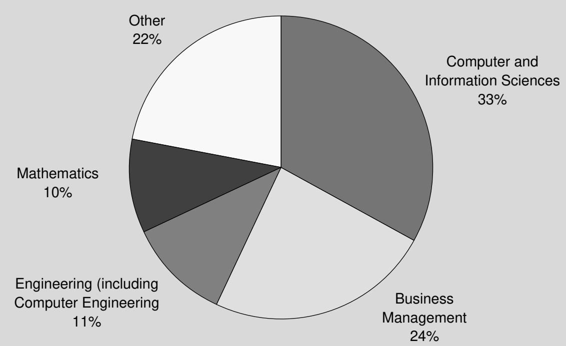
Table 5-5 is based on percentages of those with bachelor's degrees who said that their work was not related to their degree. It shows that undergraduate majors in computer science are more likely to pursue and continue in IT jobs than engineers are to pursue and continue engineering careers, or scientists are to pursue and continue scientific careers. It should not be inferred from this data, however, that pushing a larger number of students through an undergraduate major in computer science would result in IT workers with similar levels of career faithfulness to those shown in these statistics. It is hard to determine whether the additional recruits to computing will have the same skills or enthusiasm for the field as those

Table 5-5

Career Faithfulness		
	Percentage Working in that Field	
Undergraduate Major	After 1-5 Years	After 20 Years
Computer Science	70	70
Engineering	50	50
Physics	50	40
Mathematics	upper 40's	35
Life Sciences	upper 40's	35

Source: National Center for Education Statistics, *Digest of Education Statistics.*

Figure 5-3



Source: National Science Foundation, National Survey of College Graduates.

who might self-select computing without incentives.

Figure 5-3 shows that in 1992-93 only about one-third of the people in computer science or programming jobs had graduated with computer and information science degrees, according to the National Survey of College Graduates. The majority of the other two-thirds held degrees in business management, engineering, or mathematics. This is bad news for employers of IT workers, given that business and mathematics enrollments have been dropping and engineering enrollments have been flat.[65] A number of other academic disciplines are also common paths to an IT career, as box 5-2 shows. Moreover, many people noted during this study that other attributes, such as the ability to work on a team and communicate effectively, are as important as technical training.[66]

People also enter the IT workforce after working first in other occupations, especially in closely related ones such as engineering, science, and business. One study found that almost half of the persons employed in the IT workforce in 1993 who had graduated from college at least four

[65] NCES data showed that business enrollments dropped from 1,766,000 in 1992-93 to 1,233,000 in 1995-96, and bachelor's degrees in business dropped from 257,000 in 1992-93 to 234,000 in 1994-95. The number of juniors and seniors majoring in mathematics dropped from 67,000 in 1994-95 to 60,000 in 1996-97. Engineering total enrollments and total bachelor's degrees in engineering have been unchanged at about 325,000 and 65,000, respectively, between 1994 and 1997, according to the American Association of Engineering Societies. The study group has heard anecdotal evidence, but has not been able to confirm with statistical data, that although the number of bachelor's degrees in business is dropping, the percentage of these degree-holders concentrating in management information systems is increasing.

[66] See Michael C. Mulder and Doris K. Lidtke, co-chairs of a Collaborative Academe/Industry Task Force, "An Information Systems-Centric Curriculum '99: Educating the Next Generation of Information Specialists, in Collaboration with Industry," draft report, January 1999.

Box 5-2

Academic Disciplines Other than the Computing Disciplines That Offer Strong Training for IT Careers

Mathematics - graduates ususally have an excellent background in logic and analysis, and often a strong background in scientific programming and modeling.

Statistics - graduates are usually very familiar with computer usage, relying heavily on statistical packages, and are comfortable with data analysis techniques.

Engineering (other than computer engineering) - graduates generally have good mathematics and science backgrounds that involve at least some computing. They are also trained in design and analysis.

Physics - graduates generally have a strong mathematics and science background and are usually familiar with computer hardware and some programming.

Chemistry - graduates have strong science and mathematics backgrounds, and they frequently have used computers.

Philosophy - graduates have strong logical thinking ability and may have taken courses in mathematical logic that provide good training for computer theory.

Business - graduates have knowledge of the organizational characteristics and issues involving the private sector, and modern business programs integrate computing into their courses to give graduates competence in computing.

Music - graduates have learned about the manipulation of patterns and themes within constraints, which often serves as good background for programming.

Instructional design - graduates are familiar with many aspects of computers as users and developers.

Graphics arts and industrial design - graduates are familiar with user interface and human-computer interaction issues.

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

years earlier were employed in or completing training for other occupations in 1989—20 percent were in business, 10 percent were in engineering fields other than computer engineering, and 17 percent were in fields other than science or business.[67] Yet another study, by the National Software Alliance, indicated that 55 percent of electrical engineering graduates had moved into software-related jobs.

There are, unfortunately, no good data available about the third category of IT workers graduating from four-year colleges: students who major in unrelated areas, but who may have taken substantial amounts of coursework in computer and information science. These data would be useful, inasmuch as the numbers involved appear to be substantial.

A number of qualitative issues were raised in the course of this study about the four-year colleges as suppliers of IT workers:

- The growth in student majors and enrollments is stretching thin the abilities of colleges to provide adequate computing facilities.[68]

- In any academic field, the introductory course in the field has a great effect on the recruitment of students to enroll in additional courses and become majors. But first courses in computer science tend to have high attrition rates. Partly this is because students taking these courses have a wide variety of backgrounds in computing, and it is hard to present the course in a way that does not bore some students and go over the head of others. A second reason is that the introductory computer science course typically focuses on teaching programming skills. If it were to teach a sampling of the subjects that are covered as part of the major—in much the way that chemistry or physics departments commonly organize their introductory course—students might be more interested and have a more informed view of what constitutes IT work. A third reason is that some departments make this introductory course particularly challenging (a rite-of-passage course) as a way to reduce enrollment pressures in the department so that the number of students does not swamp the size of the faculty and the computing facilities available.

- Colleges are having difficulty attracting qualified instructional personnel. The recent doubling of newly declared majors and the similar increase in course enrollment will require many additional instructional staff. However, excellent opportunities in industry, together with the lack of an increase in the number of new doctorates being awarded in computer and information science, is making it difficult for schools to recruit new tenure-track faculty.

- There are many highly qualified IT workers in industry who would enjoy a chance to teach computer science or information

[67] Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," Draft Final Report, The Urban Institute, February 25, 1998.

[68] For a discussion of various issues related to IT support on campus, including compensation, recruitment, and retention of IT staff, see www.educause.edu/issues/hrit.html

systems courses in the colleges part-time, in early retirement, or as a career change. Universities already employ a large number of adjunct faculty, especially to teach lower-level courses. There remain, however, considerable additional opportunities to use adjuncts from industry to teach in all parts of the curriculum. University regulations against long-term teaching appointments outside of the tenure system and low adjunct pay scales, as well as company policies, are sometimes impediments to such teaching arrangements.

◆ The number of women and minorities, other than Asian Americans, becoming majors or even enrolling in entry-level computing courses is small. There is anecdotal evidence that, of all the IT-related disciplines, women and minorities are most willing to enroll in information systems courses and majors, but not in percentages that reflect their numbers in the general population or in the university student population. Possible reasons for the relatively greater attractiveness of information systems are fewer mathematics and science requirements than in computer science, as well as the perception that information systems involves more teamwork and is more oriented towards applications.

◆ Anecdotal evidence suggests that part-time students are enrolling at increasing rates, but no data are collected on part-time students in IT disciplines. Colleges need to offer courses at times that are more convenient to this student population, who are likely to be working during the day. One method for doing this is to make the instruction asynchronous, which is the mode of some of the distance-learning programs today.

◆ There is also anecdotal evidence that students in computing programs are increasingly likely to leave school and enter the workforce before completing their degrees. While there may be short-term gains from early employment, educators are worried that these workers will not have the basic conceptual knowledge to keep up with the rapid changes in the IT industry and that emotional or family reasons will make it more difficult for them to return to school a few years later in order to learn those basic skills.

What Is the Role of Graduate Programs in the Supply System?

The main graduate degree programs lead to either the master's or doctoral (doctor of philosophy) degrees, although a small number of students receive a degree known as the doctor of engineering degree. Graduate programs in computer science will be covered first, followed by graduate programs in other computing disciplines such as computer engineering and information systems.

The master's program prepares graduates for higher-level jobs in information technology. There are two common tracks: professional master's degrees, which are geared to meeting the needs of working professionals and prepare them for immediate entry into the practice, and research-preparatory master's degrees, which are designed to prepare students for study at the doctoral level. A typical master's program in computer science involves the completion of 10 to 12 semester-long courses. Some specialization or concentration within a broad subfield of computing, such as software engineering or networking, is possible and is often expected. Master's programs allow a student opportunities to conduct individual research (in the form of a thesis), enroll in advanced topics courses that explore boundaries of the state of the art and practice of the discipline, and participate in small group seminars that provide experience with projects, presentation, and teamwork.

For many employers of high-level information technology workers, it is the master's degree that adds the greatest value. The education in professional and research-preparatory master's programs can be very similar, but professional master's programs tend to emphasize a balance between foundations and practice, whereas the research-preparatory track gives greater emphasis to foundations. The professional master's programs sometimes has a greater emphasis on interaction with industry and local business; and, especially in information science departments, the professional-track faculty tend to be familiar with business environments.

Doctoral programs are intended to produce high-end information technology workers who possess cutting-edge knowledge of some particular technology area and are trained to carry out research. They involve additional course work beyond the master's program and rigorous examinations ensuring competency in a broad range of topics. This breadth of knowledge is complemented in the later years of the doctoral program by gaining depth of knowledge in a narrow subfield, such as software engineering metrics or verification of networking protocols. Specialization at the doctoral level may also involve other disciplines beyond the core areas of computer science, such as cognitive science or bioinformatics. Emphasis is placed on learning the skills necessary to identify important unsolved problems within the area of specialization, defining and framing them for solution, and discovering a solution through organized research. A substantial dissertation project that results in extending knowledge of the field is a critical element of the degree program.

Between the master's degree and the doctor of philosophy degree in level of training is the doctor of engineering degree in engineering schools (sometimes called the 'doctor of arts' degree in liberal arts schools). It is similar to the doctor of philosophy degree in requiring the breadth of knowledge through course work and a comprehensive exam, and depth of knowledge through additional course work and study. However, the doctor of engineering degree does not typically require a dissertation. It requires less time to complete than the doctor of philosophy degree, but still provides some of the same advanced training features. If there is continued high demand for high-end information technology workers by industry, it may be desirable to increase the number of doctor of engineering degrees awarded. Today this degree is relatively uncommon; it is used primarily to give students in doctor of philosophy programs credit for their accomplishments if they decide to leave school after their

Table 5-6

Graduate Programs in Computer Science		
Academic Year	Number of Master's Programs	Number of Doctoral Programs
1989-1990	311	100
1990-1991	314	100
1991-1992	319	103
1992-1993	316	112
1993-1994	325	117
1994-1995	339	119

Source: National Center for Education Statistics, *Digest of Education Statistics*, using preliminary data for 1990-1991 and final data for all other years. No statistics are available that break out professional from research-oriented master's programs.

course work is completed, but prior to writing a dissertation.

Academic quality and specific training offered are typically the foremost considerations when a student selects a graduate school, especially at the doctoral level. Many students entering professional master's programs are already working, and they continue to do so while they go to school. These students will often choose the best academic program close to their workplace, rather than the best academic program overall. It is common for graduate students to receive financial support in the form of fellowships, teaching assistantships, research assistantships, or company-paid tuition. These assistantships are an important part of the educational experience, providing valuable training in working with groups, making presentations, writing proposals, and gaining practical knowledge. Because stipend levels in graduate programs are significantly lower than industry salaries, some students find it difficult to justify going to graduate school, especially for the doctorate.

Table 5-6 shows the number of master's and doctoral programs in computer science in the United States. During the first half of the 1990s there was a 9-percent growth in the number of master's programs and a 19-percent growth in the number of doctoral programs. If those growth trends have continued, today there are probably about 350 master's programs and 140 doctoral programs.[69] To put these numbers into context, in 1994-95 there were 1,351 institutions awarding master's programs (in at least one discipline) and 482 institutions awarding doctoral degrees (in at least one discipline). Thus, graduate degrees are given in computer science at only about 30 percent of the institutions of higher learning that award at least one graduate degree at the master's or doctoral level. This apparent opportunity for growth must be tempered by the recognition that it requires significant numbers of highly trained IT workers to staff such programs, and that the kinds

[69] The Computing Research Association maintains the Forsythe List of Ph.D.-granting institutions in computer science, computer engineering, and closely related disciplines. The fall 1998 list counts 175 departments in the United States, as follows: computer science 111; computer engineering 16; computer science and engineering 16; computer and information science 12; electrical and computer engineering 6; electrical engineering and computer science 6; and one each for computer science and electrical engineering; electrical engineering and computer engineering; electrical and computer engineering and computer science; electrical engineering; department of engineering-systems; information science; management information systems; and information technology and engineering.

Table 5-7

Graduate School Enrollment in Computer Science	
Academic Year	Number of Students Enrolled
August 1990	34,000
August 1991	34,600
August 1992	36,300
August 1993	36,200
August 1994	34,100
August 1995	33,400
August 1996	34,600

Source: National Center for Education Statistics, *Digest of Education Statistics*, using preliminary data for 1990-1991 and final data for all other years.

of people who would make highly qualified faculty members are those who are already in high demand from industry and other universities. Most newly formed graduate programs in computer science are quite weak—and continue to be weak for some years thereafter. Perhaps the greatest opportunity is for starting professional master's programs in geographical regions where there is industry demand and where industry might be able to provide some of the instructors on an adjunct basis.

The most reliable statistics about graduate enrollments in computer science come from NSF. Table 5-7 shows that graduate enrollment in computer science has been fairly steady throughout the first half of the 1990s, at about 35,000. The ratio of full-time to part-time students is about 1:1 and has not changed much throughout this period. There are no statistics that distinguish master's students in the professional track from those in the research-preparation track, or master's from doctoral students. The Computing Research Association's (CRA's) Taulbee Survey, which is more up to date than data from NSF, shows new master's degree full-time enrollments (at the Ph.D.-granting schools) of 3,400 in both August 1996 and August 1997. This suggests that the steady master's enrollment is continuing. However, the Taulbee Survey shows 1,300 new full-time doctoral students enrolled in August 1996 (an increase of 25 percent over the previous year) and 1,400 new doctoral students (an 8 percent increase over the previous year) in August 1997. Whether these increased enrollments in doctoral programs will result in increased doctorates will depend on how successful the universities are at retaining their students in the face of a very good job market for IT workers with advanced skills.

Computer science graduate programs include enrollments of large numbers of foreign nationals. The National Software Alliance reported that, in 1994, 37.5 percent of the master's students in computer science were foreign nationals, as were 44.8 percent of the doctoral students. The CRA Taulbee Survey for that year showed that at least 41

[70] The CRA Taulbee Survey showed 41 percent full-time and 21 percent part-time foreign national students. However, the counts in the category for Asian-Pacific Islanders, which was supposed to include only domestic students of these backgrounds, looked unusually large to the computer scientists responsible for managing the survey. There is a belief, which is impossible to support or refute, that some of the students reported in the survey as Asian-Pacific Islander domestic students were actually Asian-Pacific Island foreign nationals on visas. If that is indeed the case, the percentages of foreign nationals are higher than the 41 percent and 21 percent reported.

Table 5-8

Non-U.S. Employment of Computer Science Doctorates Awarded in the United States

Survey Year	Percentage
1994	18.0
1995	15.9
1996	9.0
1997	5.5

Source: Computing Research Association, Taulbee Survey.

percent of full-time and 21 percent of part-time students in graduate programs in computer science and computer engineering were foreign nationals.[70] There are indications that this percentage of foreign nationals is slowly increasing. If a large percentage of foreign nationals return to their home country upon graduation, this would imply that a significant fraction of the doctorates produced in the United States would find employment abroad. However, as Table 5-8 indicates, there is a sharply decreasing trend of recent computer science doctorates going abroad. Clearly, many of the foreign national students are remaining in the United States to work after completing their studies.

The study group received qualitative reports—unsupported by any statistics—on changes over time in the employment practices of foreign students educated in the United States. In the 1970s it was common for these students to make concerted efforts to remain in the United States upon graduation, given that most other countries did not have good career opportunities for them. In the 1980s a number of countries, such as Taiwan and Singapore, sponsored national initiatives to build up indigenous IT industries. This led to a change in the career patterns of foreign students in U.S. IT graduate programs. The students usually remained in the United States for four or five years to gain valuable on-the-job experience to supplement their formal education, and then they would return home to take up positions of leadership. In the 1990s, with the greater entrepreneurial opportunities in the United States than in most other countries and the economic problems in Asia, there appears to be some swing back to a desire among these students to remain in the United States for the long run.

Critics of the large number of foreign students trained in U.S. graduate programs often complain that they are taking places away from U.S. students, and that the U.S. government and American universities subsidize the training of workers for other countries. There may be some element of truth in these criticisms, but there are also good reasons for the United States to continue this practice. Some of these foreign students do remain in the United States and become part of the educated professional workforce of our country. These workers give U.S. companies with global markets a competitive advantage through their knowledge of the culture and the personal contacts in their home countries. If they return home to take up senior positions after completing their formal education or after working a few years in the United States, they can also be helpful to American companies because they have American contacts a familiarity with U.S. practices. This increases their effectiveness in working with U.S. companies wanting to enter their home country's market.

Table 5-9

Number of Master's and Doctoral Degrees Awarded in IT Fields, 1992-1995

Master's Degrees

Academic Year	Computer Science	Computer Engineering	Management Information Science and Data Processing	Other Business Information Systems
1992-1993	10,163	–	1,592	208
1993-1994	10,416	1,071	1,877	263
1994-1995	10,326	1,040	2,012	394

Doctoral Degrees

Academic Year	Computer Science	Computer Engineering	Management Information Science and Data Processing	Other Business Information Systems
1992-1993	805	–	0	0
1993-1994	810	123	0	0
1994-1995	884	140	3	3

Source: National Center for Education Statistics, *Digest of Education Statistics*.

Turning from enrollments to degree production, table 5-9 shows the number of computer science master's and doctoral degrees produced earlier this decade. At that time, master's production was fairly steady, at slightly more than 10,000 degrees per year. More recent data from the CRA Taulbee Survey suggest that this level of production continued into 1997, possibly with a small increase (less than 10 percent in 1997).[71] However, Taulbee data suggest a decrease in Ph.D. production of about 10 percent since the peak production in 1992.[72] The study group has estimated that about 70 percent of students who enter graduate school in computer science eventually graduate with either a master's degree or a doctorate.[73]

Graduate degree programs in other areas of information technology (computer engineering, management information systems, and other business information systems)

[71] Extrapolation is needed to figure out trends from the Taulbee data. The Taulbee numbers had to be increased to include the 10 percent to 20 percent of the PhD-granting departments not responding to the survey, scaled up to consider master's degrees produced by other than PhD-granting departments since the latter only produce about one-third of the master's, decreased for inclusion of computer engineering degrees in the statistics, and further decreased for degrees awarded by Canadian schools.

[72] CRA Taulbee statistics and NSF/SRS statistics track in close parallel with Department of Education statistics, but are about 10 percent higher.

[73] Assume two years for a master's degree, and the initial two years plus an additional four years for the doctorate. Data show about 11,000 graduates per year and 35,000 enrolled. Yield = (21,000 (2 x 10,500) + 3,200(4 x 800))/35,000, which equals approximately 0.69.

together produce about one-third as many master's degrees as does computer science, and about one-eighth as many doctorates. There is evidence of steady growth in the number of master's degrees in management information systems, but data are not available to determine if this trend has continued in the past several years. There is anecdotal evidence that many students, both those with technical and those with non-technical undergraduate training, choose MBA programs for graduate study. In this case, their supplementary IT education is more likely to be in the form of continuing education, tutorials provided by professional organizations, or company training.

A number of qualitative issues concerning graduate education arose during the course of this study:

- Many universities are having difficulty attracting qualified students, especially U.S. students, for graduate study in computing fields. The study group estimates that only 11 percent of those who receive bachelor's degrees in computer science in the United States attend computer science graduate school in this country.[74]

- Stipends for graduate study are low, given the amount of time required to complete the requirements and the salaries available in industry.

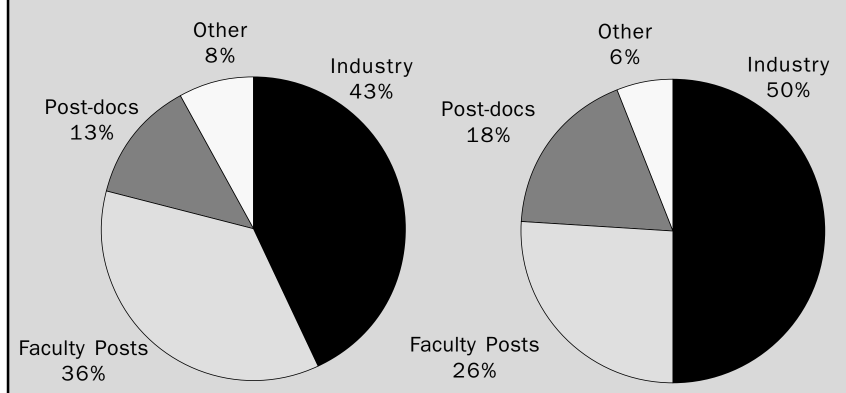
- Traditionally, qualifying for financial aid has been based on the expressed willingness of students to continue on for the doctorate. The rationale is that faculty prefer doctoral students over master's students because they are likely to be better colleagues and be available to work on research projects for longer periods of time with greater involvement and responsibility. However, this preference may negatively affect the ability to build strong professional master's programs, which industry particularly values. (This distribution pattern for financial support is still in force in many computer science and computer engineering programs. However, in some professional schools where there is a strong emphasis on master's programs, different sources and criteria have been established for providing financial aid to master's and doctoral students.)

- Anecdotal data suggest that universities are having an increasingly difficult time retaining their doctoral students to complete the degree, but without statistical evidence it is hard to assess the extent of the problem. This phenomenon appears to be tied to the attraction of industrial positions with high salaries, good

[74] This is an estimate based on the following argument: Assume that 90 percent of the foreign nationals who do graduate study in computer science in the United States did their undergraduate study outside the United States, and that 100 percent of U.S. students in graduate school in computer science did their undergraduate work in the United States. The fraction of foreign nationals in graduate school in computer science is approximately 50 percent. These statistics imply that only about 55 percent of those in graduate school did their undergraduate work in the United States. In 1995, the number of computer science bachelor's degrees produced was 24,769 (NSF 98-307, Table 46). In 1996, there were 4,908 full-time computer science students in graduate school for the first time (NSF 98-307, Table 26). The fraction of U.S. bachelor's students going to graduate school is then approximately .55 x 4908/24769 = 0.11).

Figure 5-4

Career Choices of Computer Science Ph.Ds, 1994 and 1996



Source: National Center for Education Statistics, *Digest of Education Statistics*

facilities, and interesting work; and also to the fact that academic research has taken an increasingly short-term focus, so that it is not as differentiated from industrial research as it used to be. Historically, computer science graduate programs attracted many able students who wanted to work on major research problems that were more likely to have long-term than short-term payoffs.

◆ IT faculty are being overloaded with work, which has a negative effect on their ability to spend time mentoring their doctoral students. Multiple factors contribute to the overload: the rapidly increasing undergraduate enrollments in computer science; the increased demand on computer science faculty to help their university to integrate information technology into its own central management and enterprises; the increased demand to help other departments incorporate information technology into their academic programs; and the increased pressure to obtain sponsored research. The overload also makes it more difficult to recruit and retain good faculty. In addition, faculty may be more reluctant to participate in cross-disciplinary programs, which might be good for computer science and for the university, for fear that this simply invites additional demands on their time.

◆ Several people reported that the attractiveness of being a faculty member is rapidly diminishing, and that many of the brightest students are choosing not to enter academic careers once they witness first-hand the demands on their faculty mentors. As figure 5-4 shows, there was an increasing tendency from 1994 to 1996 for computer science Ph.D.s to choose industrial careers fresh from graduate school. The 1997 CRA Taulbee Survey indicates that this trend is continuing. It shows that 53 percent of those whose post-Ph.D. employment was known accepted industrial positions, compared with 48 percent the year before. Table 5-10

Table 5-10

Faculty Flight to Industry from Ph.D. Granting Departments of Computer Science and Computer Engineering

Year	Number
1993-1994	40
1994-1995	44
1995-1996	44
1996-1997	53

Source: Computing Research Association, Taulbee Survey.

shows a similar trend of faculty leaving their posts in increasing numbers in recent years, although the numbers are small.

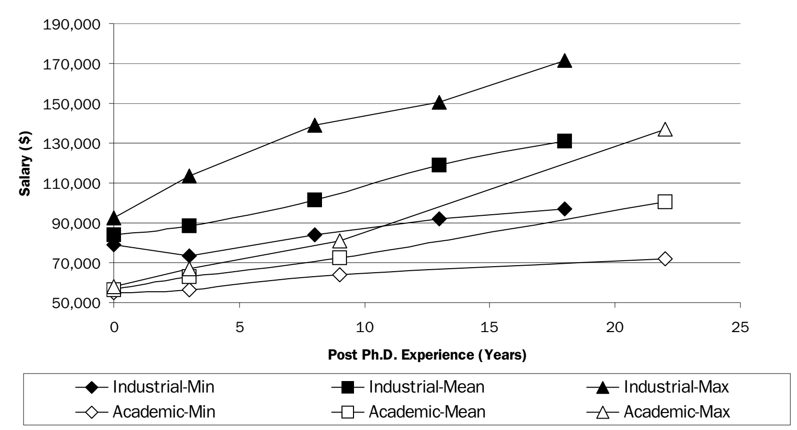
◆ DARPA officials have indicated that in certain key applied areas, such as software engineering and database systems, universities have reported difficulties retaining faculty and support staff, including principal investigators in charge of DARPA contracts. If this problem worsens, it could have a detrimental affect on universities carrying out mission-critical research for the Department of Defense and other government agencies.

◆ Base faculty salaries tend to be low compared with base industry salaries (see figure 5-5), although faculty members do have a chance to obtain summer salaries and earn extra income by consulting. If faculty are able to obtain summer salaries and a moderate amount of consulting revenue (amounting to a not-unusual 43 percent of their base salary), then the total salary for an academic computer scientist is roughly comparable to the total salary (base salary plus incentive bonuses, stock plans, and other variable salary) of a computer scientist in an industrial research laboratory. However, it may not be easy for a beginning faculty member to secure summer and consulting income. Starting nine-month faculty salaries were mostly in the $50,000 to $65,000 range for the 1998-99 academic year.[75] While these are good salaries, they are not outstanding, given the talent and amount of training a new graduate in computer and information science has acquired. There is some salary compression, so that mid-career faculty (associate professors) often earn only slightly more than newly hired assistant professors. This compression causes morale problems and makes industrial alternatives appear that much more attractive.

[75] The computer science faculty salaries are taken from the annual CRA Taulbee Survey, which is published annually in the March issue of *Computing Research News*. See http://www.cra.org/statistics/. The Association for Information Systems, IS Worldnet, and the University of Pittsburgh have begun an annual salary survey for MIS faculty. The 1998 results can be found at http://www.pitt.edu/~galletta/salsurv.html

Figure 5-5

Twelve-Month Industrial Salaries Compared to Nine-Month Academic Salaries



Source: The academic salary figures are taken from the 1997-98 CRA Taulbee Survey for the twelve top-ranked computer science departments, assuming that an assistant professor has an average of three years' experience, an associate professor has an average of eight years' experience, and a full professor has an average of twenty-two years' experience. The industrial salary figures are taken from the 1997 CRA Industrial Salary Survey.

Chapter 6. Supply—Non-Degree Programs

When people think of higher education, they generally think of students enrolling in colleges and universities to earn traditional formal degrees. As the previous chapter discussed, there is a well-established system of formal higher education for information technology (IT). The explosion of non-degree programs in information technology, however, is less well known. Figure 6-1 shows that work-related training is offered to nearly three times as many people as are enrolled in traditional post-secondary education. Figure 6-2 shows that even among those who are in the post-secondary educational system, less than one-third of those enrolled are traditional full-time students.

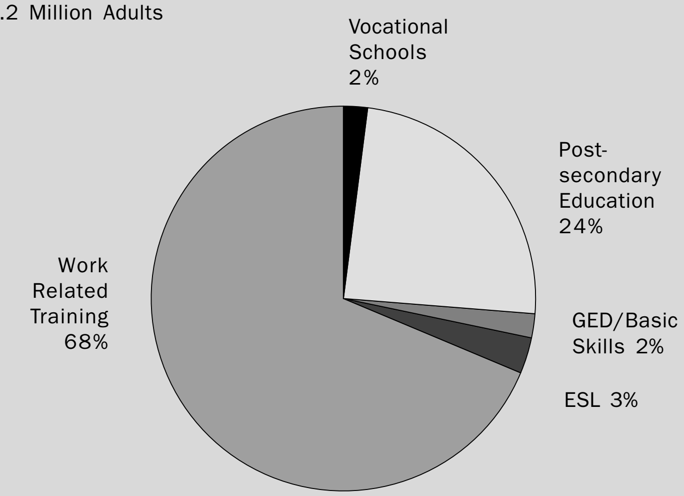
Non-degree programs take many forms: certificate and enrichment courses taught by colleges and universities at every level; training provided by private educators, ranging from individual consultants to large commercial educational firms; training associated with specific IT products; businesses that train their own workforce; and courses offered via distance education. The length and purpose of these programs also vary widely—from the half-day course or shorter lecture and seminar that give an overview of a specific topic, to the two-week course that provides a working knowledge of a focused topic, to the six-month certification program that offers in-depth knowledge of a focused topic, to the apprenticeship that may last several years and result in significant career progression.

These forms of education appear to be growing very fast. However, because they are so varied and non-traditional, there is a lack of reliable data with which to evaluate their growth rates. For the most part, these forms of training provide IT workers with knowledge and skills required to meet specific vocational needs. Training time is usually relatively short and costs generally quite low. The training is unlikely to provide longer-term foundational knowledge that would support a life-long career. People sometimes enroll in these programs at their own initiative to enhance their careers, and often because their companies have asked them to acquire new skills and knowledge. Typical

Figure 6-1

Adult Education

Total=59.2 Million Adults

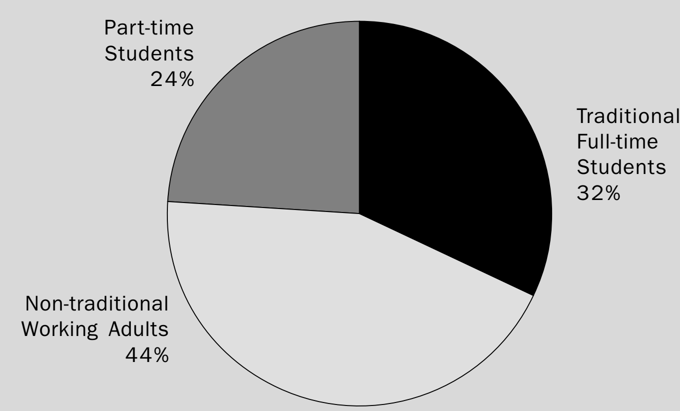


Lehman Brothers as taken from Jeanne C. Meister, *Corporate Universities: Lessons in Building a World-Class Work Force* (New York, NY: McGraw-Hill, revised and updated edition, 1998).

Figure 6-2

Post-secondary Education by Type of Student

Total=14.6 Million Adults



Lehman Brothers as taken from Jeanne C. Meister, *Corporate Universities: Lessons in Building a World-Class Work Force* (New York, NY: McGraw-Hill, revised and updated edition, 1998).

examples include the individual who is seeking:

- training for a specific career (e.g., computer operator);

- career advancement (e.g., a computer operator training to be a computer network administrator);

- movement toward a professional career (e.g., a computer operator seeking a job that normally requires a degree);

- continuing education to maintain up-to-date technical skills (e.g., an engineer seeking to learn about a new technology);

- a career shift (e.g., a mechanical engineer retraining to become a software engineer); or

- specific product information or usage skills (e.g., how to use a specific information technology product).

Companies are also using this kind of training to impart knowledge about the corporate mission and practices, to improve employees' non-technical skills such as communication and teamwork, or to give them non-technical knowledge of best practices in their industry.

What Non-Degree Programs Do Traditional Colleges and Universities offer?

Non-degree programs are offered at every level from two-year colleges to graduate school. Certificate programs and short courses, both specializing in some particular area within information technology (such as networking, electronic commerce technology, or software project management).[76]

The typical IT graduate certificate program is an adult continuing education program, directed at a person who possesses a bachelor's degree (but not necessarily in an IT major). A working knowledge of information technology may suffice to perform well in these programs. At the end of the course of study, the student is expected to have learned the basic theory and concepts of the particular area of IT under study, and to be familiar with the state of the art and trends. Graduates should have acquired enough knowledge of the area that they can keep their knowledge current as the field develops. The program will typically include between three and six courses at the post-baccalaureate level, and possibly an independent project. Completing these programs should extend the range of jobs available to the graduates to include various

[76] See IDC IT Training and Educational Services reports on "Worldwide and US IT Training and Educational Markets and Trends" and "The Business of IT Certification: Market Potential and Trends." The reports can be purchased by contacting ctoffel@idcresearch.com.

occupations that involve creating, extending, or tending technical information systems.

Many two-year colleges have certificate programs in information technology. These programs train people for occupations that are considered highly skilled in comparison to most occupations but are, in fact, among the less skilled kinds of IT work. They generally involve the tending or extending of technical information systems, and carry titles such as computer programmer, office systems specialist, network technician, computer repairer, multimedia and Web designer, or vendor-specific certified technicians (such as a Microsoft or Novell technician). The students entering these programs include persons who are just beginning their education or their careers, those who have now received non-IT bachelor's degrees and may have some work experience but who want a better-paying or more fulfilling job, as well as others.

The offerings of the four-year colleges and teaching-oriented universities are somewhat harder to classify. They are targeted somewhere between the offerings of the research university and the two-year college, and they contain elements of each. They offer moderately low-level courses in topics such as Web design or vendor-specific certification, undergraduate-level courses in topics such as Java programming, and post-baccalaureate courses similar to those offered in the research universities. Often these courses are tailored for specific companies that are located near the schools. This has become a major activity and significant source of revenue for some schools, such as the American University in the Washington, DC, region and Bentley College in the Boston area.

What Other Groups Supply Non-Degree Programs?

In addition to two- and four-year colleges and the universities, many other groups supply non-degree training in information technology. One is the vocational training school, such as DeVry or IIT Training Institute. These schools offer programs typically aimed at individuals who do not have a college degree. The nature of the instruction is primarily vocational, and the training programs typically prepare the students for specific jobs in the lower-end occupations in the IT workforce.

Private educators also supply training. Some are individual consultants, others are well-established firms such as Software Learning Associates. These private educators offer mainly consulting services or short courses focused on specific IT skills—ranging from project management, to computer programming, to people management skills, to the use of specific tools and IT products. Courses are available at every level of skill, directed at virtually every occupation within the IT field.

Product suppliers often provide training for people who will use or maintain their products at customer sites. Many IT products are very complicated, making training essential in these cases.

Concerned about the technical capabilities of people who are using and maintaining their products, IT vendors such as Microsoft and Novell have developed more than 150 vendor-specific certification programs for technicians. Certification assures customers that they are hiring qualified people to use or maintain these IT products. These certification programs often are licensed to other kinds of suppliers, such as independent educators and two-year and four-year colleges. A two-year college might want, for example, to offer a certificate program in networking, and it must choose some particular technology to use in teaching general principles; to meet this need, it might choose to license a particular vendor's training program. This can be very attractive to college administrators or state legislators because the vendor may be willing to: guarantee employment for all students who successfully complete the certification process; provide a completely developed curriculum and curricular materials; help train the school's faculty to teach the program; and perhaps even provide instructional equipment free of charge or at reduced cost. These vendor-specific programs may also have a downside, however. Some educators are concerned because of the undue influence they are having on the design of curricula.

What Is the Role of Corporate Universities in Training and Educating IT Workers?

Corporate universities have existed since the 1950s, but during the last decade the number has multiplied from 400 to more than 1,000 (at the same time that more than 200 accredited colleges have gone out of business).[77] Corporate universities may now be the fastest growing sector of higher education. They have developed because of the widely perceived need in the corporate sector for life-long learning, and the belief of many employers that the existing post-secondary system is not able to deliver what they want their employees to learn. There is a widely held view in corporate management that most workers in the future will be "knowledge workers," who will need to keep abreast of the latest developments in their rapidly changing field; thus these managers regard continuous education as an important way to keep the company competitive. Given that many companies headquartered in Europe and Asia are spending two to five times as much on training as American companies, this is often viewed as a global competitiveness issue.

Ten years ago corporate universities usually had physical campuses, just like accredited

[77] The material for this section is taken primarily from Jeanne C. Meister, *Corporate Universities: Lessons in Building a World-Class Work Force* (New York, NY: McGraw-Hill, revised and updated edition, 1998).

universities. Some still do. Motorola University, for example, has campuses around the world. Others, such as Dell University or Sun University, have no campus at all. The emerging view of the corporate university is as a process rather than a place—a process for providing life-long learning to all who are involved in the company's well-being (employees at every level, customers, suppliers, dealers, distributors, wholesalers, etc.). Physical locales are increasingly being considered not so much as the principal places of learning, but as a good place to carry out one specific aspect of learning—the sharing of best practices. These physical classrooms are supplemented by many technical ways of delivering courses at a distance.

Corporate universities use many technologies in the learning process, such as satellite broadcasts, video and audiotapes, knowledge databases, tutorial CD-ROMs, and Internet/intranet-based courses. The amount of learning carried out through the use of technology is increasing rapidly, and a recent survey indicates that half of all corporate training will occur in this fashion by the year 2000.[78] This new way of delivering learning works well for employees, suppliers, and customers who are spread throughout the world and who cannot afford the time or expense to come to a physical site for training. It also fits well with the rapid pace at which the business world, and the knowledge required to be effective in it, is changing.

More than 4 million people already learn through corporate universities and their learning partners (traditional training firms, accredited universities, for-profit educational firms, etc.). Nearly half of all corporate universities already have some kind of alliance with an accredited educational institution, and 40 percent of corporate universities expect to start granting accredited degrees in collaboration with an accredited college or university. The degrees they confer range from the associate's through the master's level. For example, AT&T School of Business partners with the University of Phoenix, which is one of the fastest growing for-profit educational firms (having grown from 3,000 to 40,000 students in the past decade). AT&T employees can take courses that count toward a degree at more than 50 University of Phoenix campuses and learning centers around the country. The corporate universities regard the traditional colleges and universities as suppliers, just like their suppliers of raw materials, parts, and services. They bring all suppliers into their educational program to instill shared values and approach. Thus Motorola partners with various two- and four-year colleges not only for the traditional teaching services these schools can provide, but also so that the schools will learn what skills and knowledge Motorola wants to impart to its workforce.

What corporate universities are teaching is driven by what the companies believe they need most in order to succeed in business today. In this respect, corporate universities differ markedly from traditional post-secondary education, which has basic education as its

[78] Annual Survey of Corporate Future Directions, as cited in Meister.

primary focus. Some technical skills are taught in the corporate universities, but much of what is taught is non-technical. The corporate universities seek to develop corporate citizenship (learning the cultures, values, traditions, and vision of the company), provide a contextual framework to the company (learn the company's customers, competitors, and industry's best practices), and teach core competencies. These competencies include:[79]

- learning skills
- communication and collaboration
- creative thinking and problem-solving
- technological literacy
- global business literacy
- leadership development
- career self-management

The direction in which corporate universities are headed is clear from examples of four types of programs that have been successfully placed in practice. The examples are not taken from the IT industry and do not apply specifically to IT workers, but it is clear that these approaches could and probably will be applied in this domain.

1. Customized executive educational programs, ranging from short courses to full-fledged MBA programs, allow corporations to customize a program that uses its own corporate culture and company-specific case studies in the courses. This is what the Whirlpool Corp. has done in collaboration with the University of Michigan, Indiana University, and a French educational institution.

2. Some corporations ally themselves with colleges and universities to develop an accredited, customized training curriculum that teaches the exact skills the corporation needs for specific job categories. For example, Megatech Engineering has joined with Central Michigan University to develop a bachelor's degree program in automotive vehicle design to alleviate a perceived shortage of automotive designers. Megatech Academy, which is located on the premises of Megatech Engineering's vehicle design building complex, has received accreditation from the State of Michigan to award this bachelor's degree. Megatech employees can also take these courses toward a design certificate.

3. Corporations and universities are beginning to form consortia so that a group of companies within an industry can gain from a single corporate university, or so that one or more companies can take advantage of faculty talent from a collection of universities. For example, the Southern Company and eleven other companies in the Atlanta area have formed a consortium with Emory University for a three-week training course spread over a four-month period to teach corporate strategy, global business environment, and leadership skills. United Healthcare and United Technologies have entered into a consortium with Rensselaer Learning Institute, which brokers

[79] Meister, p. 13.

courses from Boston University, Carnegie-Mellon University, Stanford University, and MIT through Interactive Compressed Video technology available to the 200,000 United workers at specified work sites.

4. Some corporate universities have decided to become accredited on their own. An example is the Arthur D. Little School of Management, formed originally to handle the corporate training requirements of Arthur D. Little clients around the world, and now an accredited program of The International Association of Management Education.

The corporate universities are able to respond to change much more quickly than the traditional colleges and universities. Corporate university courses are sometimes placed online within a week of their being adopted, whereas it usually takes a college a year to implement a new course. Dell University updates its catalog of offerings every two weeks, compared with every one to two years for the typical university.

What Is the Role of Distance Learning in Educating the IT Workforce?

The success of corporate universities is likely to be dependent on distance learning. Distance learning may also become a significant tool for those who supply traditional post-secondary education. Correspondence schools have existed since the nineteenth century, but the introduction of many new technologies is raising new possibilities and challenges for educators.[80]

Distance learning has advanced in a number of ways. In the self-learning area, there are improved methods, such as broadcast television, rule-based software, CD-ROMs, and video, for delivering distance education. It is sometimes difficult, however, to know how much someone has learned from courses based on these media. Many believe that students learn more effectively through interactive processes, such as interactive television. The interactive approach has several advantages in that an instructor can directly apply many of his or her skills from the traditional classroom, and the only start-up costs are the capital equipment and the leased line. (There is no major up-front curricular development cost, although it may take some effort and learning, including some new skills, to produce visuals that can be televised effectively.) One shortcoming is that the instruction is restricted to a specific time and place. To overcome these limitations, some people are proponents of asynchronous distance learning, which can occur at any time and any place, within certain limits. The challenge is to build an affordable, user-friendly system that allows

[80] This section is based largely on discussions with Michael Teitelbaum and Frank Mayadas of the Alfred P. Sloan Foundation, an organization that is working to make distance learning a reality.

interactive teacher-student and student-student exchanges about problems and concepts.

Most asynchronous distance learning courses in operation today are experimental. However, a number of projects are now under way to develop systems that can be placed into regular operation, meet realistic learning objectives, and are not too expensive for students. Most of these systems involve Web-based learning, perhaps supplemented by a course textbook or some other technology such as CD-ROM. Schemes have been developed, for example, that allow an instructor to ask questions, require answers to be turned in, grade assignments and give individual students feedback, and post model answers. There are also ways for all the students to see answers given to an individual student's questions, and ways for students to work with one another. It appears that experimentation will continue about how to build such systems, and continued progress is likely.

Some of the barriers to implementing distance learning systems have been overcome in the past five years. Communication expenses—for dedicated data lines or national toll-free numbers provided by the supplier, for example—were extremely high for early systems. Today, a student can sign up for $20 or less per month with a local Internet service provider and have communications access. The costs of the computers used by students to obtain their education have also fallen, from more than $3,000 to less than $1,000 for an adequate machine. As more people become familiar with the Internet and the World Wide Web, it is likely that prospective students and employees will increasingly consider distance learning a convenient alternative to more traditional educational methods.

While progress has been made in distance education, some barriers persist. Video delivery systems need to improve; the pedagogy of distance learning warrants further study; and economic factors are still a consideration. Institutional barriers can also be strong—in fact, IT companies themselves have not been leaders in the adoption of asynchronous distance education.

It is too early to tell whether teachers will like this format. One potential advantage is that once a question has been answered for one student, it can be recorded permanently and made available on demand to all the other students. The asynchronous mode also seems well suited to teaching technical subjects because a student who gets stuck on a problem can put it aside to think over or ask for a hint from the instructor or other class members. Instructors have also found that the format works for group discussions, and that technical design problems can be solved by the class as a whole and result in satisfactory designs. Many of the instructors who have tried asynchronous distance learning have liked it, but they are the early adopters that one encounters with any new technology; and sometimes the reactions of the larger community are not as positive as those of the early adopters.

The Alfred P. Sloan Foundation is working with thirty-five degree-granting institutions, including Stanford, Pennsylvania State, Drexel, Johns Hopkins, and the University of Illinois, to develop distance learning programs. Here are three promising examples:

◆ Drexel University is offering a master's degree in information systems entirely by asynchronous distance learning. The courses, exams, and degree awarded are exactly the same as Drexel offers in a traditional classroom format on campus—and the success rate in the two formats is comparable. Currently the distance learning format is marketed only to major corporations in the Philadelphia-New York area, such as Metropolitan Life, Vanguard, Cigna, Unisys, and Merck. These companies select programmers and middle-level managers from their information systems departments to enroll in the program. The companies find this arrangement are extremely attractive because the employees can continue to work full-time and take their courses from home or the office. Employees do not have to take a leave of absence from work for a year or two to complete the degree, and they typically finish the course of study in about the same amount of time as a part-time student who comes to campus for classroom instruction.

◆ The University of California-Berkeley Extension Program offers more than 200 asynchronous learning courses at reasonable prices to individuals. These courses, which are distributed by America Online, range across many disciplines. A few of them concern information technology. However, Berkeley Extension is not authorized by the University of California to issue degrees or certificates, whether the courses are taught online or in the classroom.

◆ The National Advisory Coalition for Telecommunications Education and Learning (NACTEL) has recently reached an agreement to support an asynchronous online Associate of Applied Science degree in telecommunications. NACTEL is a partnership of large telecommunications companies and unions (Bell Atlantic, Communications Workers of America, GTE, International Brotherhood of Electrical Workers, SBC, and US West) that represent more than 500,000 telecommunications workers. NACTEL is concerned about a serious shortage of trained telecommunications technicians able to handle the rapidly changing telecommunications technologies of advanced telephones, caller ID, voice mailboxes, Internet services, fax machines, and modems. The degree program will begin with 100 students in 1999, and it is expected to grow to 3,000 students by the third year. Pace University, with guidance from NACTEL, will prepare courses in technical mathematics, telecommunications, electronics, and networks.

Issues

A number of qualitative observations and issues about non-degree training arose in the course of the study:

◆ There is a lack of standards, consistency, and quality control in the non-degree training market. There are essentially no standards or accreditation processes. Individuals and employers do not have a good understanding of what they are buying, and employers have a difficult time evaluating the knowledge and skill sets employees have acquired from such training. Standards alone do not guarantee quality programs, but it is an important first step. What exists today is basically a *caveat emptor* market.

◆ There are low barriers to entry in providing certain kinds of training, such as short courses. In some cases all that is needed is a meeting room and a single, knowledgeable instructor. Companies who want training for their employees will often supply the meeting room, and it is not costly for the trainer to rent a classroom at a hotel or community center on a daily basis, if need be. Ease of entry into the training domain, however, also makes it more difficult to enforce minimal standards on the kind of training offered.

◆ Non-degree programs provide a good opportunity for experienced practitioners to pass on their knowledge to others. Such programs are popular with early retirees because of the flexibility they offer—working out of the home, flexible schedules, and setting one's own pace.

◆ While it is expensive to run a full-scale corporate university, many of the associated technologies are rapidly becoming less expensive. Tools for course preparation (e.g., for Web-based courses) are being developed, and a body of knowledge is accumulating about how to use these technologies effectively. Thus it is anticipated that the costs, effort, and knowledge to run corporate universities will lessen to a point that many more workers will have access to them.

Is Retraining Occurring, and if so, How Long Does it Take To Retrain for an IT Job?

Little information is available about the nature and extent of industry's commitment to retrain IT workers, although some is available on corporate retraining in general. It appears that companies are increasingly prepared to devote resources to retraining in order to keep their existing workforce up to date and productive. There is little evidence, however, that companies are willing to spend resources on entry training that would allow a person with good general skills to change occupations at company expense. Many companies still believe it is the individual's responsibility to learn the basic technological skills the occupation requires before being hired. Even with the basic occupational skills in place, it typically takes a new employee six months (or more, in the case of positions that involve advanced skills or extensive education) to learn enough about the organization and the particular job to be fully productive. Some companies, especially small ones, have trouble affording the costs of carrying a less-than-fully productive employee for six months or a year, much less having the responsibility as well for providing the basic occupational skill training.

The news is more positive when considering job seekers. There seems to be a large pool of people willing to retrain for IT work. Presumably this is because of the widely perceived view about the availability of jobs, good wages, the professional nature of the work, the opportunities to do it without relocating, the increasing number of people who have some familiarity with computers and networks, and the intrinsic interest of the work. An examination of three institutions (Northern Virginia Community College, the Applied Management Institute in Omaha, and Clayton College and State University in Georgia) confirms that significant numbers of persons twenty-five years or older will elect to pursue IT preparation if it is available at times, in places, and in ways that accommodate the constraints of their lifestyles. These schools have seen people with both baccalaureate and advanced degrees seeking both credit and non-credit IT courses and training.[81]

It does not take all that long for someone with good academic skills to retrain for many IT occupations. The length of these training programs varies. For example, about six months of full-time training can prepare an individual with some scientific programming experience to become an entry-level Unix systems administrator. A two-year associate's degree program can enable a high school graduate to work as a computer programmer or a computer maintenance technician. The most advanced IT occupations are not generally accessible to people with this kind of retraining, but instead require an advanced degree in an IT-related discipline that may take many years to complete.

[81] The Winter 1999 catalog for the Loudoun Campus of Northern Virginia Community College (only one of several of their campuses) gives a sense of the popularity of these programs. The catalog of IT courses ran for more than 35 pages (about 300 courses). They included courses associated with certificate programs in Cisco networking, client/server computing, C/C++, Oracle database, Microsoft Solution Developer and Programmer, Powerbuilder, Networking, Virtual Reality, Web and Internet Programming, Computer Aided Design, Multimedia, PC Engineering and Computer Repair and Support, Digital Photography, Configuration Management Unix, and GIS; plus noncertificate program courses in application development and design, databases and spreadsheets, Internet topics, office applications, publishing and graphics, ISO 9000, and general computing.

Chapter 7. Women, Minorities, and Older Workers

Several groups of Americans are represented in the information technology (IT) workforce in percentages that are far lower than their percentages in the population as a whole. These include African Americans, Hispanics, Native Americans, and women generally. There are also open questions about the representation of older workers in the IT workforce.

How Do Women Relate to the Worker Shortage?

If the number of women in the IT workforce were increased to equal the number of men, even the tremendous shortages of IT workers noted in the ITAA studies could be filled. However, according to the Department of Commerce, only 1.1 percent of undergraduate women choose IT-related disciplines as compared to 3.3 percent of male undergraduates.

Tables 7-1 and 7-2 provide statistics about the percentage of women being educated in IT fields. Table 7-1 shows the number of women in formal degree programs in computer and information science at all U.S. colleges and universities, whereas table 7-2 shows the number of women in formal degree programs in computer science and computer engineering at only the Ph.D.-granting institutions. Table 7-2 works from a smaller sample, but it provides more current information. The percentages of women in bachelor's and master's programs are much lower in table 7-2, which is attributed not to any methodological problem with either data set, but rather to the fact that table 7-1 includes information systems degrees and table 7-2 does not. There is anecdotal evidence that women are entering information systems programs in greater percentages than computer science and computer engineering programs. The reason given is that information systems is perceived as more people-oriented and more attuned to the uses of information technology, whereas computer science and computer

Table 7-1

Number of Degrees Awarded in Computer and Information Sciences by Level and Gender						
Academic Year	Ph.D.s Awarded	% Women	MS Awarded	% Women	BA/BS Awarded	% Women
1984-1985	240	10.0	6,942	28.9	38,589	36.8
1986-1987	374	13.9	8,481	29.4	39,590	34.7
1989-1989	551	15.4	9,414	28.0	30,454	30.8
1989-1990	627	14.8	9,677	28.1	27,257	29.9
1990-1991	676	13.6	9,324	29.6	25,083	29.3
1991-1992	776	13.8	9,534	27.8	24,578	28.7
1992-1993	808	14.7	10,171	27.1	24,241	28.1
1993-1994	810	15.4	10,416	25.8	24,200	28.4

Source: National Center for Education Statistics, *Digest of Education Statistics.*

Table 7-2

Degrees Awarded in Computer Science By Level and Gender						
Academic Year	Ph.D. Awarded	% Women	MS Awarded	% Women	BA/BS Awarded	% Women
1984-1985	326	11.0	–	–	–	–
1985-1986	412	12.1	–	–	–	–
1986-1987	559	9.7	–	–	–	–
1987-1988	744	9.0	5,159	–	12,687	–
1988-1989	807	13.3	5,457	–	10,606	–
1989-1990	907	12.6	5,116	–	9,681	–
1990-1991	1,074	12.1	4,993	–	9,353	–
1991-1992	1,113	11.3	5,121	–	9,813	–
1992-1993	997	13.3	4,523	–	8,218	–
1993-1994	1,005	15.6	5,179	19.1	8,216	17.9
1994-1995	1,006	16.2	4,425	19.7	7,561	18.1
1995-1996	915	11.7	4,260	20.0	8,411	15.9
1996-1997	894	14.4	4,430	22.3	8,063	15.7

Source: Computing Research Association, Taulbee Survey. 1984-86 Ph.D. numbers for CS&CE departments, all other years CS departments only.

engineering are more focused on the technology itself.[82]

One of the obvious patterns in these two exhibits is that the percentage of women entering the computer science pipeline and earning the bachelor's degree in these IT fields has been dropping steadily since 1984. While the number of computer and information science degrees awarded decreased every year between 1986 and 1994, the decrease is occurring at a faster rate proportionately for women. This is in contrast to general trends in the graduation figures of U.S. colleges and universi-

[82] For a more general discussion of information systems versus computer science programs and the demand for them, see http://www.ne-dev.com/ned-01-1998/ned-01-enterprise.t.html

ties during these same years, when the percentage of bachelor's degree recipients who were women increased from 50.8 percent to 54.6 percent. It is also in contrast to the trends in scientific and engineering disciplines generally. The decrease in bachelor's degrees awarded to women has also affected the number of women in the graduate degree pipeline, contributing to the decrease in women completing a master's degree in the computer and information sciences area. The percentages at the doctoral level have stayed somewhat flat, with a reduction in the number of U.S. women apparently offset by an increase in the number of female foreign students entering the system at the graduate level. There are no reliable data on the number of women in the IT workforce.

The decline in women engaging in formal IT training since 1984 is in sharp contrast to the pattern of the late 1970s and early 1980s. In that period, concerted efforts were made to recruit women to the field, and these efforts resulted in a rapid increase in the number of women students. Thus the subsequent decline in the percentage of women entering the field is especially disheartening. However, the experience of the early 1980s shows that programmatic efforts can make a significant difference. There has been much speculation about the causes for the decline in women entering the IT training pipeline.[83] Some of the reasons that have been suggested include:

- The lack of equipment in the high schools, so that women do not gain early experience with the technology.

- The way in which computers are presented to many high school students—often in terms of aggressive or violent games. These games tend to involve a small set of skills, which boys seem to enjoy mastering by playing the games again and again, while girls seem to get bored with the repetitiveness.

- The lack of K-12 teachers and guidance counselors who are knowledgeable about the wide variety of career paths and opportunities in IT.

- The image of computing as involving a lifestyle that is not well rounded or conducive to family life.

- A perceived image of IT work as being carried out in an environment in which one has to deal regularly with more competition than collaboration.

- Differences in socialization between men and women about whether they are performing well academically, which may encourage men and discourage women from the study of information technology in college—even when the male and female students are performing equally well academically.

- A perception of computing as a solitary occupation, not well integrated into social discourse or social institutions.

[83] Some methodologically rigorous research on this issue is under way. See Allan Fisher and Jane Margolis, Computer Science Department, Carnegie Mellon University, on "Women in Computer Science: Closing the Gender Gap in Higher Education" (http://www.cs.cmu.edu/~gendergap).

Table 7-3

Ph.D. Degrees Awarded in Computer Science and Engineering By Minority Ethnicity

Academic Year	Ph.D. Awarded	African-American		Hispanic		Native American		Asian or Pacific Islander		Other	
		#	%	#	%	#	%	#	%	#	%
1984-1985	326	3	1.0	7	2.1	-	-	-	-	92	28.2
1985-1986	412	6	1.5	6	1.5	-	-	-	-	151	36.7
1986-1987	559	3	0.5	9	1.6	-	-	-	-	197	35.2
1987-1988	744	6	0.8	8	1.0	-	-	-	-	281	37.8
1988-1989	807	0	0.0	12	1.5	-	-	-	-	299	37.0
1989-1990	907	4	0.4	11	1.2	-	-	281	31.0	148	16.3
1990-1991	1,074	8	0.7	26	2.4	-	-	349	32.5	151	14.0
1991-1992	1,113	11	1.0	17	1.5	-	-	412	37.0	131	11.8
1992-1993	997	7	0.7	13	1.3	-	-	319	32.0	118	11.8
1993-1994	1,005	14	1.4	9	0.9	0	0	154	15.3	76	7.6
1994-1995	1,006	9	0.9	28	2.8	1	0	149	14.8	92	9.1
1995-1996	915	11	1.2	27	3.0	5	0	143	15.6	59	6.4
1996-1997	894	6	0.6	3	0.3	0	0	107	12.0	60	6.7

Source: Computing Research Association, Taulbee Survey.

- A perception that software jobs are not family-friendly (e.g., long hours, lack of awareness of opportunities for telecommuting and other flexible schedules).

- Courses in mathematics and science that are requirements for degree programs in computer science and computer engineering, which women have not been encouraged to pursue based on outdated stereotypes of aptitude and interest.

- The lack of women role models.

- The large percentage of foreign-born teaching assistants and faculty, some of whom have cultural values that are perceived as not being supportive of women being educated or joining the workforce.

- Concerns about safety and security felt by women and their friends and families about women working alone at night and on weekends in computer laboratories.

How Do Minorities Relate to the Worker Shortage?

The number of persons from most minority groups either training or working in information technology occupations is very low. One probable reason is the small number of minority students moving through the educational pipeline. Considering only those students who graduate from college, the percentages of Native Americans, African Americans, and Hispanics receiving a degree in computer or information science is actually higher than the percentage among non-Hispanic white males. However, this promising statistic is more than offset by the fact that minorities attend college in much lower percentages than whites do. Table 7-3 shows the low percentages of African Americans, Hispanics, and

Native Americans training in IT-related disciplines.

Many of the reasons that discourage women from IT careers also apply to minorities. There are very few minority role models in information technology. Minority students are less likely to have computers at home or at school on which to gain early exposure to information technology.[84] Students who attend historically black colleges and universities face limited computing facilities, compared with the average U.S. college or university. But there are other reasons as well. For example, minority students who want to devote their lives to helping their communities do not regard information technology as a social-conscience field. Students with that goal are much more likely to train for careers in law, medicine, or politics.

One intriguing piece of anecdotal evidence is that African Americans who have received doctoral degrees in computer science over the past decade have overwhelmingly chosen (more than 90 percent) industrial rather than academic careers. Speculation is that companies have done a better job than universities at making diversity an integral part of their organizational values and salaries are better. Also, minority employees are more likely to be able to get on with their work in companies without being burdened by heavy committee workloads that they would experience in universities that are reaching out for diverse representation.

How Do Older Workers Relate to the Worker Shortage?

There is a common perception that information technology is an occupation for younger workers. We all have the image of the young programmer staying awake on massive doses of caffeine while undertaking a thirty-six-hour programming session. There is some truth to this image. Programming is increasingly becoming a skilled entry-level position, and many of the programming positions—but by no means all of them—are populated by recent college graduates.

There is a less savory side to this image, however—that of the programmer being washed up and put out of a job by the uncaring employer by the age of 40. How are older information technology workers treated? Unfortunately, there is very little credible evidence on which to judge. Given the high demand for IT workers and the premium that companies claim they place on teamwork, communication skills, and knowledge of the business and industry, one would expect companies to welcome older workers. It has been reported to us that less than two percent of programmers over

[84] Minority students who do have computers in their schools are more likely to use them for repetitive math skills, instead of simulations and real-life applications of mathematics concepts. See Educational Research Service, "Does it Compute? The Relationship between Educational Technology and Student Achievement in Mathematics."

age 40 are unemployed, but we have been unable to track down the hard data to support this statement.

If one considers older unemployed workers in other professions who want to become IT workers, the scant and anecdotal evidence presents a much less rosy picture. The downsizing of the defense industry and of corporate America more generally during the 1980s created unemployment for a significant number of electrical engineers. The IEEE-USA has recently completed a survey of its unemployed members, although the sample size is small (335 of 1,288 = 26 percent). Their study indicates that—holding constant highest degree, Internet access, dependence of job on government funding, whether respondent is retired/ voluntarily unemployed, and type of job search technique—each year of age above 45 adds three weeks to the duration of unemployment.[85] The IEEE has been appropriately cautious in reading evidence of age discrimination into these statistics:

Overall, the survey indicates that age has a persistent effect on the duration of unemployment, but it cannot be determined whether that is attributable to productivity differences, price differences, age discrimination or some other factor. For example, the longest duration of unemployment occurs in the defense industry and the second longest unemployment period occurs in the aerospace industry. Older engineers are more likely to be working in aerospace and defense and these industries are more likely than others to rely on government funding; therefore industry, and not age alone, can account for unemployment.[86]

Given the lack of statistical data or other close examination of this issue, the study group looks forward to the results of the recently inaugurated National Research Council study that will include an examination of older workers. Until then, all discussion of this issue is likely to be speculative.

[85] Chris Currie, IEEE-USA External Communications Supervisor, personal communication, December 11, 1998.

[86] Annette Codispotti, Assistant Editor, "Survey Gives IEEE-USA a Picture of Unemployed Engineers," *The Institute, IEEE*, February 1999.

Chapter 8. Seed-Corn Issues

Is the Strong Industrial Demand for IT Workers Harming the Educational System?

Many educators, industrial laboratory leaders, and government science officials are concerned that the high industrial demand for information technology (IT) workers will siphon out of the educational systems many students who would otherwise pursue an advanced degree. This diminishes pool of people who will join the university faculties that perform basic research and teach the next generation of students. This problem is compounded when industry also successfully recruits current faculty members, including junior faculty who would become the academic leaders of the profession in the coming decades. This is known as the "seed-corn" problem—an analogy to those who consume too much of this year's crop, reserving too little for next year's planting. A similar situation occurred in 1980.

In 1980 the Bureau of Labor Statistics reported 1.4 million employees in "computer occupations" in the United States, and estimated that the number would grow to 2.1 million by 1990. By this date, after 15 years of continuing expansion in academic computing programs, about 25,000 bachelor's degrees, 5,000 master's degrees, and 250 doctoral degrees in computer science were being awarded annually in the United States. The estimated annual demand for these categories was 50,000, 30,000 and 1000, respectively, and a significant concern arose about whether this demand could be met in the coming years.

The supply shortfall was being covered by people educated in related disciplines who acquired, in various ways, the skills necessary for an IT career. However, as technological change continued to accelerate, it became evident that a higher percentage of workers in the field would need an education that focused on computing and information technology. A closer examination of academic programs in 1980 showed that, although the numbers of bachelor's and master's students and degrees each year were expanding rapidly, the number of doctorates in computer science had leveled off at 250. Significant numbers of graduate students were leaving the doctoral programs to go directly into industry. Less than half of the new doctorates were accepting faculty positions, which appeared insufficient to sustain the academic programs needed to meet the demands of undergraduate and master's degree programs. The chairs of essentially all of the Ph.D.-granting computer science departments in the United States and Canada gathered together and identified three immediate needs:

- a computational infrastructure for faculty and graduate students comparable to that found in the best industrial research labs;
- funding to support Ph.D. students throughout their study period; and
- new faculty positions to accommodate the burgeoning undergraduate enrollments, while continuing to provide the faculty adequate time (comparable to that provided in other scientific and engineering disciplines) to supervise graduate students and conduct research.

In large part because of the unanimity of the agreement on the needed steps, they were taken swiftly. The National Science Foundation (NSF) took the lead in providing computational infrastructure support, which was significantly supplemented by grants from companies. NSF and companies established new programs of doctoral student support (with several companies making the support conditional upon the student's commitment to pursue an academic career). Universities added significant numbers of faculty positions to cover the growing enrollments. By 1990 the annual Ph.D. production had quadrupled to about 1,000.

However, the problems persisted. By the mid-to-late 1980s, it was becoming apparent that the growth in faculty was not being accompanied by a commensurate growth in funding for faculty research and graduate education activities. Also, the call for full funding for Ph.D. students had not been completely answered. As the number of students increased, this lack of funding became increasingly apparent. Although the new steps taken were on track at this time to enable the production of 1,000 Ph.D.s per year, they would prove inadequate for building an academic enterprise sufficiently large to both continue the production of Ph.D.s and educate the growing number of undergraduate and master's students. For example, a 1983 study showed that the computer science bachelor-degree-to-faculty ratio was twice that in electrical engineering and four times or more the ratio in any other related discipline. In addition, the computer science full-time-graduate-student-to-faculty ratio was 50 percent higher than that of electrical engineering and of all engineering, and three times higher than the ratio of any other related discipline. Such workloads made alternate careers for computer science faculty very attractive indeed, and discouraged students from choosing such a faculty career.

With this history providing perspective, there are early signs of another cycle of "eating our seed corn." The conditions are similar: aggressive recruiting by industry that is luring high-quality undergraduates away from considering graduate school; doctoral-caliber graduate students leaving graduate programs after completing only a master's degree; faculty shying away from high-pressure teaching positions; and burgeoning undergraduate enrollments that are creating large class sizes, an inflated faculty-to-student ratio, and overcommitted faculty.[87] Not surprisingly, there is a downward trend in the number of computer science doctorates awarded annually during the 1990s (1,074 awarded in 1990-91, 894 in 1996-97).[88] The number of new doctoral graduates entering academia is slightly more than 40 percent if postdoctoral and academic research positions, as well as faculty positions, are included. This percentage has not been increasing, which means that the total number entering the teaching field is lower. Meanwhile, the number of faculty positions being advertised has skyrocketed. Advertisements in *Computing Research News,* for example, have doubled over the past two years.

Other signs of a seed-corn problem are appearing. Universities have already experienced severe shortages in several faculty areas, including networking, databases, and software engineering, and faculty recruiting is becoming much more difficult.. There are fewer qualified applicants, positions are taking longer to fill, and some are going unfilled. The general attitude of the computing research community at the moment is to monitor the situation closely, until the data and qualitative evidence make it more apparent that a serious seed-corn problem does exist. If this is determined, then actions similar to those taken in the 1980s by government, industry, and academia working together may be warranted.

The situation today is, however, different in some respects from 1980.[89] Today, IT facilities in universities are more like those in industry than they were in 1980; and a healthy research program in experimental computer science now exists in the universities. However, the focus of university research has become much more short-term than it used to be, making it less different from industrial research; this change has removed one incentive for faculty and graduate students to remain in the universities. High-level IT professionals today employed across a much larger number of employers, including many outside the IT sector. This makes it more difficult for industry to work together, as companies did in the 1980s, to restrain the raiding of faculty and graduate students from universities.

[87] See the anecdotal account of this situation in Bronwyn Fryer, "College Computer Science Enrollment Skyrockets," *Computerworld*, October 22, 1998.

[88] CRA Taulbee Surveys.

[89] The President's Information Technology Advisory Committee has addressed some of these issues in its report to the President. See http://www.ccic.gov/ac/report/.

What Are the Sources of Data on IT Workers?

Data are available from three primary sources: the federal government, professional societies, and the private sector. In a separate project, the National Science Foundation (NSF) funded the Commission on Professionals in Science and Technology (CPST) to develop an Internet-based *Guide to Data on Scientists and Engineers*.[90]

Federal data. The most relevant federal data on information technology (IT) workers are provided by NSF's Science Resources Studies (SRS) division, the National Center for Education Statistics (NCES; Department of Education), and the Bureau of Labor Statistics (BLS; Department of Labor).

Data on the employment of those working in the U.S. on temporary visas are very limited and were not particularly helpful to this study. The relevant agencies include the U.S. Department of Justice, Immigration and Naturalization Services (issuance of H1-B visas to individuals) and the U.S. Department of Labor (employer applications for H1-B visas).[91]

NSF has a wealth of data on scientists and engineers.[92] The largest amount of worker-related NSF data is on doctoral scientists, since this has long been considered the principal professional degree for independent researchers. Data also are collected on those who hold a baccalaureate or a master's in science or engineering. The data are maintained at the direction of Congress to provide an inventory of human capital for national prosperity and security, and a source of information for policy formulation by other agencies.

[90] For further details and hyperlinks to the data sources described in this section, this guide can be accessed at www.cpst.org.

[91] See: www.oig.dol.gov/public/reports/oa/1996/foreign_labor_cert.pdf for a concise report subtitled, "The System is Broken and Needs to be Fixed."

[92] www.nsf.gov/sbe/srs

NSF's Science Resources Studies division oversees the Survey of Doctorate Recipients (SDR), a biennial survey of a representative sample of those who have received doctorates in the United States in a science or engineering field.

In addition, NSF oversees the Survey of Earned Doctorates (SED), which is an annual population survey of individuals receiving doctorates that year in science or engineering. SED data are stored in a Doctoral Records File (DRF), from which the sample for the SDR can be pulled for longitudinal follow-ups and for replenishments and retirements every two years.

NSF also collects workforce-related data on individuals with bachelor's and master's degrees in science and engineering fields, as part of the biennial National Survey of Recent College Graduates (NSRCG) and the National Survey of College Graduates (NSCG).[93] Data at all degree levels have been merged recently into a database called SESTAT, which is accessible from the Web site.

In addition to the surveys of individuals described thus far, NSF annually collects institutional-level data on enrollments and degrees from the baccalaureate and above in science and engineering at U.S. universities. These data are available in a database called CASPAR, which is accessible from the Web site.

The National Center for Education Statistics focuses on enrollments, degrees, faculty counts, and numerous other statistics on the status of the educational enterprise in the United States.[94] The annual *Digest of Education Statistics*, available on their Web site, contains voluminous data. NCES also sponsors periodic longitudinal surveys that follow up on the work experiences of samples of selected cohorts of high school and college students.

The Bureau of Labor Statistics provides employment data and outlooks based primarily on data collected from employers and extrapolated into the future BLS data are not usually sorted by degree level or degree field, since the reporting burden on employers would be somewhat onerous.[95] BLS is planning a national job vacancy survey in 1999 for the first time in this country.

Professional society data. The Computing Research Association (CRA) conducts an annual survey of Ph.D.-granting departments in computer science and computer engineering to ascertain enrollments, degrees, faculty size and salaries, as well as the placement of doctoral graduates as reported by departments.[96]

The Engineering Workforce Commission of the American Association of Engineering Societies collects data on enroll-

[93] The National Survey of College Graduates is conducted by the Census Bureau for the National Science Foundation as a baseline survey every ten years; the participants are then followed up biennially during that ten-year period.

[94] http://nces.ed.gov

[95] http://stats.bls.gov

[96] www.cra.org/statistics

ments, degrees, and salaries of engineers at all degree levels.[97]

The American Society for Engineering Education surveyed the employment experiences of recent engineering doctorates as part of an NSF-funded CPST project on outcomes of doctorates.[98] CPST also coordinated a comparable survey of computer science doctorates.[99] The National Association of Colleges and Employers (formerly the College Placement Council) collects data from college and university placement/career centers covering job and salary offers made to new graduates, primarily at the baccalaureate level.[100]

The Council of Graduate Schools conducts an annual Survey of Graduate Enrollments, which includes data on applications to graduate schools, as well as enrollments and degrees granted.[101]

The International Association of Managerial Education collects data on information technology graduates from business schools.

Private sector data. Private data sources include Abbott, Langer & Associates,[102] Computerworld,[103] and Datamation.[104] The first is a professional survey research organization that specializes in salary surveys of employers; the latter two organizations publish IT-related magazines and periodically survey their individual readers. These salary surveys are particularly interesting for a project such as this because they reflect the diversity, inconsistencies, and change among job position titles in organizations that employ IT workers.

Other data sources. The Information Technology Association of America (ITAA) is a trade association that conducts an annual compensation survey with the help of William M. Mercer, Inc.[105] As with the private sector surveys, the ITAA survey includes paragraph-length descriptions of an extensive inventory of more than 80 IT and related job descriptions.

As part of the Cooperative Institutional Research Program of the Higher Education Research Institute (HERI) at the University of California, Los Angeles, data have been collected annually since 1966 from freshmen in the U.S. on their intended majors and career plans [106] The American Council on Education is a sponsor. Periodic, longitu-

[97] www.aaes.org/ewc

[98] www.asee.org/data

[99] www.nextwave.org/survey. The survey results are posted, with related articles, in the *Communications of the ACM* (September 1997 and November 1998).

[100] www.jobweb.org

[101] www.cgsnet.org/vcr

[102] www.abbott-langer.com

[103] www.computerworld.com

[104] www.datamation.com

[105] Results are available at www.itaa.org

[106] www.gseis.ucla.edu/heri/heri.html

dinal follow-ups of selected cohorts have been performed as research funding has allowed.

What Are the Limitations of Existing Data on the IT Workforce?

Numerous and serious problems with the supply and demand data make it difficult to establish a sound basis for making policy decisions. Much of the data coming from non-federal sources exhibit the following problems:

◆ *The domain of workers studied was too narrow.* A number of data studies—some of which are well done—are available on specific regions (IT workers in Georgia,[107] software workers in Washington State,[108] etc.) or specific categories of workers (National Software Alliance study,[109] U.S. International Trade Commission study of software and service workers, etc.). Unfortunately, it is not clear that the geographical regions or categories of workers covered in these studies provide results that are representative of the national IT worker situation.

◆ *There were methodological problems with the gathering or analysis of data.* A number of studies are flawed because the sample size or the response rate was too small, questions were framed in ambiguous or misleading ways, or final results were calculated from raw data in a questionable fashion. The U.S. General Accounting Office has rightly criticized the low response rates of the ITAA studies, for example. This does not mean, however, that the conclusions ITAA reached are false; it means only that they cannot be assumed to be true. The statistical results do not have the reliability or weight of evidence that one could draw from a survey with much higher response rates.

Considering both domain and methodology, data collected and processed by federal organizations such as BLS, NSF, and the Department of Education typically have the highest reliability. However, even these data sets have serious problems from the standpoint of being useful to decision-makers interested in IT worker issues.

◆ *The data are not timely.* It takes time to collect high-quality survey data, to achieve high response rates, and to clean and analyze data properly. Also, because of the expense involved, some surveys are only conducted every other year. As a result, in the case of NSF workforce data, the most recent data available in late 1998 were from 1995. In a field that is changing as rapidly as information technology, data that are three years old have limited value. Data that are at most one year old are needed in

[107] Ephraim R. McLean and Scott L. Schneberger, *ICAPP Strategic Industry Needs Assessment: Information Technology*, Board of Regents of the University System of Georgia, December 1997.

[108] See: http://www.wsa1.org/gotwork/wasoft.htm

[109] National Software Alliance, “Software Workers for the New Millennium: Global Competitiveness Hangs in the Balance,” Arlington, VA, January 1998.

order to understand the current status of this rapidly paced IT industry. While the delays are in part understandable, ways need to be found to speed up data collection and analysis.

◆ *Worker categories have not been updated sufficiently to reflect the current state of IT work.* Survey researchers and policymakers must make a trade-off between updating surveys to be more responsive to today's marketplace versus maintaining consistency from survey to survey so that results can be compared historically. The Standard Occupational Classification (SOC), which is used by all federal agencies, had not been changed from 1980 until 1998. Older occupational categories have been preserved over time.

◆ *Even apparently good occupational categories, such as computer programmers, are too broad and ill defined to allow policymakers to understand key issues well.* Different kinds of programmers, for example, are not necessarily interchangeable because their work involves different skill sets. Companies have had only modest success at retraining COBOL programmers to be effective Java programmers because of the wide differences in the programming methodology of the two languages. It is not clear that there is much chance of convincing the federal data collectors to break their categories into smaller ones to resolve this issue; but if the professional community collects data, it should keep this issue in mind.

◆ *The levels of data aggregation, in either what data were collected or what data were reported publicly, are often problematic.* For example, computer science is sometimes combined with mathematics, other times combined with the physical sciences, and still other times with engineering. In most cases, based on the purposes for which the data were originally collected, this is understandable. But it posed a challenge for researching this study.

◆ *Data have generally been collected by the federal government only in relation to earlier issues of policy concern. These data do not provide an adequate basis for making current policy decisions.* For example, non-degree training such as certificate programs, short courses, and corporate universities are an increasingly important part of the supply system for IT workers. Because these training venues have not been important to national policy in the past, federal statistics about them do not exist.

◆ *Even in cases where there had been previous policy issues, data collection is sometimes inadequate.* One example concerns H-1B visas. There are no statistics available on how many temporary workers are actually in the United States on H-1B visas, only on the number of approved labor certificates and the number of visas that were awarded. Nor are data available on how many of the visa-holders are doing IT work.

◆ *Data on the demand for IT workers are especially poor.* Companies are reluctant to report data about their need for workers or disclose the effects of a shortage on their business. This is considered proprietary information. Companies worry that if it were made public, it could harm their public reputation or be exploited by their competitors.

◆ *The mismatch between supply and demand data, as collected by different* *federal agencies, is problematic.* One major frustration in researching this report was trying to match data broken out by educational degree fields (computer science, information systems, software engineering, etc.) and levels (bachelor's, master's, etc.), with data based on occupational classifications or job position descriptions (programmer, systems analyst, computer scientist, for example). The study group's attempts to cross-tabulate by education and occupation had limited success. NSF was the only source that had useful occupational data broken out by educational background. BLS data are occupationally oriented, while NCES data are educationally oriented.

◆ *Using online, publicly available databases is too challenging.* The Internet can provide access to microdata or other "raw" data. Researchers can analyze data collected to answer one set of questions in an attempt to answer another new set of questions. However, most current systems are not yet very user-friendly in terms of search engines, time required to process requests, variable naming conventions, table or report generation, etc. In most cases, users have to take considerable time to learn the systems and cannot easily retrieve data.

Chapter 10: Recommendations

As noted in the Executive Summary, these recommendations are offered on the basis of the study group's collected experience and study of the supply of information technology (IT) workers. It is hoped that at a minimum they will spark productive discussion. They are organized by intended audience. A summary of the recommendations can be found in box 10-1 following this chapter.

1. FEDERAL AND STATE GOVERNMENTS

1.1. Data-collection practices must be improved.

The federal government is by far the most reliable and comprehensive source of data on the supply of and demand for information technology (IT) workers, and it continues to be in the best position to collect these data. However, current data are not as useful as they could be because they are not timely, they are not sufficiently comprehensive, they do not employ adequate categorizations in many cases, and there is insufficient comparability among data collected by different agencies. There needs to be better coordination among federal agencies when collecting data about supply and demand, and data should be collected in a way that permits meaningful comparison across data sets—no matter which federal agency collects the data.

1.2. A new system for tracking the demand for and supply of IT workers should be created.

The Bureau of Labor Statistics (BLS), the National Science Foundation (NSF), and the National Center for Education Statistics (NCES) have done a good job using their traditional approaches, but those measures are not sufficient to fully inform decision-makers. It is the federal government's responsibility to bring together representatives from industry and academia to create a new system that will better meet the needs of policymakers for supply and demand data.

1.3. Data collected must be comprehensive to be useful for policy deliberations.

The data need to cover all parts of the United States. This has not generally been a problem in federal data, but is sometimes a problem with data from other sources. The regional studies reviewed by the study group appear to be useful in their geographical domain, but they do not adequately account for interstate movements that could be extensive. On the supply side, data need to be collected not only about formal degree programs in IT-related disciplines such as computer science and information systems, but also about other disciplines that train many IT workers, such as business, engineering, and science. Data should also be collected about non-degree programs, including those offered by for-profit and other non-traditional organizations. The data need to cover all U.S. demand for IT workers, not only that of companies in the IT sector. Companies outside the IT sector and all small companies may be under-represented in existing demand statistics. The demand data should be broken down into categories that are useful to suppliers for setting their curricula and enrollment sizes.

1.4. The Standard Occupational Classification (SOC) categories for information technology occupations need to be reviewed and refreshed on a regular basis.

These categories currently are of marginal use in connection with many IT policy issues. Although the task is onerous and there are potential risks to the longitudinal continuity of data, classifications of IT workers should be reviewed every couple of years and refreshed as needed to reflect the current state of the field. Classifications must be based not on job titles, but on the tasks performed and the skill sets required to do these tasks. Some important sources of supply are currently not tracked well (e.g., information systems bachelor's degrees and continuing education enrollments).

1.5. Federal and state governments, with industry involvement, should improve IT-related training mechanisms at the K-12 educational levels and keep them current. Counseling, teacher training, curricula, and computing facilities all need improvement relative to information technology.

Students are being unconsciously eliminated from the candidate pool of IT workers by the knowledge and attitudes they acquire in their K-12 years. Many students do not learn the basic skills of reasoning, mathematics, and communication that provide the foundation for higher education or entry-level jobs in IT work. A number of students who have some or all of these basic skills do not consider IT careers because they believe (often incorrectly) they cannot succeed in this area, or because they have misperceptions about the opportunities or the nature of the work. It is in the nation's interest to have as large a potential pool of IT workers as possible. In any case, many of the skills learned in preparing for a possible career in information technology are skills that will serve people well in other careers, and more generally as citizens in the twenty-first century.

This is not a task solely for government—at any level—to do alone. There is a large role that industry can and should play in local communities in providing new and used equipment, enriching curricula, supplying adjunct instructors, and training teachers. In addition to direct financial investment in the public schools, governments can sponsor programs to teach K-12 students about IT opportunities, develop model programs, disseminate information about best practices, stimulate academic-industry partnerships, and make the public aware of the importance of improved education. A great deal has already been accomplished in this area, particularly in providing adequate computing facilities to the schools. It appears that the schools have made more progress in obtaining facilities than they have in the other three areas: adequate counseling, teacher training, and curriculum development.

1.6. The federal government, and especially state governments, should help to strengthen traditional higher educational programs in IT-related areas.

The higher educational system is a tremendous national resource and remains the foundation for providing IT-workers. It is basically healthy, but needs some augmentation in the IT areas. The government can encourage colleges and universities to expand and create degree and non-degree options at all levels that better prepare students to meet industry needs. These programs can simultaneously provide up-to-date basic skills training, while being more attentive to the workforce objectives of industry.

The need seems to be greatest at the associate's and master's degree levels, which are more career-oriented than the baccalaureate and the doctorate. Fewer than one-third of the community colleges are offering associate degree programs in IT-related areas. Many universities could offer professionally oriented master's programs that better meet the needs of local industry for mid- to high-level IT workers. Governments can have a profound influence on the programs offered by the formal educational system, using the power of leadership by elected officials, incentives added to current funding programs to colleges and universities, new funding programs, statistics about the need of programs, and development and communication for best practices.

1.7. Government can help faculty and educational staff adapt to the new demand for IT-trained students.

There is a long-standing tension, not only in IT-related curricula, between basic educational and career goals. U.S. colleges and universities are the envy of the world, which indicates that many aspects of the curriculum are already balanced appropriately, but there is room for improvement. For example, in doctoral programs many faculty believe that their goal is to produce clones of themselves—graduates who have the same skills and aspirations as they do. These programs tend to produce too many people who are trained for careers in research universities, and not enough who are trained to enter industry or to teach in the teaching-oriented institutions that train the majority of undergraduates who enter the IT field. At the associate degree level, the faculty need to review whether vendor-specific curricula are meeting their basic educational needs.

1.8. Government should help to attract more students into graduate programs in IT-related disciplines.

Although enrollments have increased slightly in the past several years, universities are still having difficulty recruiting students—especially those who are U.S. citizens—to attend graduate school in IT-related programs. They also are experiencing increasing difficulty in retaining their graduate students long enough to complete their degrees, especially the Ph.D. degree. The percentage of U.S. students in these graduate programs has recently fallen to less than fifty percent. Government should provide new fellowships and traineeships to encourage graduate study in these disciplines, especially for U.S. citizens. It has been the general practice to base fellowship support in computing disciplines (as in other science and engineering disciplines) primarily on intellectual and scholarly merit. There are sound reasons for this practice, but other factors, including the intention to enter critical areas (such as teaching) and geographical location, should also be considered. The National Research Service Awards offered by the National Institutes of Health might be one model to consider for information technology.

1.9. Government should help faculty and staff cope with the greatly increased demand in the IT area.

Many university faculty in IT-related disciplines are feeling heavily overworked, which is affecting their ability to carry out their principal duties of teaching and research, and also causing some faculty to leave the profession. Contributing factors include heavy undergraduate teaching loads (compared with other science and engineering disciplines) due to lack of faculty, large classes, heavy committee work assignments to help out the university central administration and other university departments with their expanding IT needs, lack of adequate support staff to help with teaching laboratories, increased pressure from university central administrations to bring in external funding, and the need to be constantly writing funding proposals because of the small, short-term grants given by federal agencies. Federal and state governments could ease this situation by providing funding for support staff, both to the faculty themselves and to their departments, and by having larger individual grants that cover longer periods of time.

1.10. The federal government, and NSF in particular, must be vigilant and prevent a seed-corn problem in IT-related disciplines.

Many members of the computing community believe that IT graduate students and faculty are being attracted to jobs in industry in increasing numbers, and there is worry that there will not be adequate teacher-scholars left to train the next generation of IT workers (the so-called "seed-corn" problem). There are preliminary signs of a seed-corn problem. This is similar to the one computer science experienced around 1980, when there was a flight from academic to industrial careers, leaving the community wondering who would teach the next generation of students. If it becomes clearer that there is a seed-corn problem today, it will be up to government, industry, and academia to work together to fix the problem. NSF is in the best position to assess the situation and to lead solution efforts, if needed. The key to preventing the problem is to make graduate study and a faculty career attractive to well-qualified people. This means making the work interesting and the work environment favorable. In 1980 this involved better computing facilities for research, more federal funding for both research and graduate student support (especially at the schools at greatest risk—those with mid-level rankings), an emphasis on experimental research, and voluntary restraint against raiding by the major industrial employers of computer science doctorates.

The situation today is similar, but not identical to the situation twenty years ago. There is not as great a need today for better computing facilities for research or for more experimental research, but there is a need for more adequate funding for long-term research and the environment to support it. A voluntary restraint program in industry may be harder to achieve this time, however, because the number of companies hiring doctorates in IT-related fields is much greater today than twenty years ago and the hiring companies are scattered across many industries, rather than being heavily concentrated in the computer manufacturing sector.

1.11. Federal and state governments must enhance the research climate in the universities.

A strong research milieu is essential to producing the next generation of creators of new and innovative ideas in information technology. By making universities a more attractive place for both faculty and graduate students, the likelihood of a seed-corn problem is diminished. Healthy research programs also have a strong impact on undergraduate education, both in the classroom and through involvement in the research. The report of the President's Information Technology Advisory Committee (the PITAC Report) provides a set of recommendations for enhancing research in the nation's universities.[110] This study is in full agreement with those recommendations, which are not repeated here.

1.12. Federal and state governments should actively encourage universities and industry to form a variety of partnerships to train the IT workforce.

Much of the work that needs to be done to train the IT workforce in the future should occur through partnerships between the academic and industrial sectors: industrial advice to universities on their curriculum; industrial employees teaching part-time; industry providing equipment and support

[110] "Information Technology Research: Investing in Our Future," President's Information Technology Advisory Committee Report to the President, February 24, 1999 (http://www.hpcc.gov/ac/).

assistance; university programs teaching additional career-oriented material; operating specialized, company-specific programs; and assisting companies in establishing internal educational programs. Government organizations can facilitate these kinds of collaboration.

1.13. The government should encourage the development of programs in academia and industry that attract underrepresented groups to IT careers.

If underrepresented groups—including women, Native Americans, Hispanics, African Americans, and perhaps older workers—were entering IT occupations in proportion to their numbers in the American population, the supply of IT workers in the United States would be much more adequate. This study does not take a position either way on affirmative action programs, but it is clear (from the programs in the 1980s to encourage women to enter the computing field) that such programs can be successful in increasing the supply of qualified IT workers.

1.14. Special efforts should be made to utilize the skills of older workers.

Older workers are a potential source of supply of IT workers that could and should be tapped to a greater extent than it currently is, although no one seems to have good estimates of the number of such workers. (The study group looks forward to the results of the study just now being undertaken by the NRC with support from NSF, which will include an examination of this issue.) No doubt many older workers have well-developed organizational and communication skills, which means that retraining could be completed quickly for these older workers—at least those with some technical background—to enter IT occupations. Government retraining programs to provide these skills to older workers may be cost effective. Such programs may have a particularly salutary effect in lessening the burden on individuals and communities created by lost jobs in the downsizing of the defense industry. These programs might counterbalance a perception that an IT career has a short duration and is only for the young.

2. HIGHER EDUCATION

2.1. Colleges and universities should keep their focus on providing strong basic education.

In the face of the rapidly changing world and even more rapidly changing IT field, it may seem impossible or irrelevant to provide a basic education that will endure. There is no question that it is difficult and that the nature of a basic education must evolve. The collected experience of the study group and observations of others, however, strongly indicate that the best preparation is still a basic education that provides its graduates with a solid foundation for life-long learning in multiple disciplines and skills.

2.2. Universities must recognize that there is a fundamental IT-related shift occurring

in the economy and in most professions, and that they must reallocate resources for better and more extensive training in this area.

It is not surprising that university central administrations are chary to support departmental requests for additional resources. Resources are scarce in higher education, and reallocations tie up resources for long periods of time in bricks-and-mortar or capital equipment that need to be maintained, or commitments to the salaries of tenured faculty that may last thirty years. Nonetheless, universities must recognize that interest in IT-related disciplines is not a fad, but will continue to grow well into the next millennium as information technology continues to grow in prominence in our society. Some of that growth is occurring right now, as the doubling in newly declared computer science majors over the past two years attests. Not all the growth in institutional programs needs to be placed in the traditional IT disciplines, such as computer science and engineering. Some growth might occur in new interdisciplinary programs and departments, or in distributing information technology throughout the university, into various existing faculties and disciplines. The specific approach will need to be made on an individual basis, depending on local circumstances. But wherever in the academy this instruction is located, the colleges and universities should plan on significant, continuing allocation and reallocation of resources into IT-related faculty and curricula.

2.3. Higher education should provide faculty support to revise their curricula to provide more and better paths in the training of IT workers, as well as to provide better IT education for all students.

Most faculty have been doing their best to keep the curricula current, but the rapid rate of change and the press of other responsibilities make this task increasingly difficult. Some amount of information technology should be made a part of all basic education programs. Knowledge of the basic concepts of information technology is now almost as important as knowledge of the fundamentals of mathematics. This issue is not addressed in this report, but readers are referred to the recently released National Research Council report, *Being Fluent With Information Technology*.[111] The higher educational system needs to provide a variety of training paths to IT careers. The system will be successful to the extent that it can accommodate students who have different interests, educational and vocational objectives, levels of technical ability and preparedness, and levels of self-confidence in their path to an IT career. By making the field more open to students with different objectives, backgrounds, and confidence levels, the field is more likely to attract students of all kinds.

2.4. Faculty in IT-related disciplines need to rethink their

[111] National Research Council, *Being Fluent With Information Technology*, Washington, DC: National Academy Press, 1999 (www2.nas.edu/cstbweb).

introductory undergraduate courses.

One barrier to attracting students to major in IT-related disciplines is the way in which some IT-related departments, especially computer science and computer engineering departments, introduce the subject to students. Faculty understandably do not want to water down their programs in order to attract students, but they sometimes mistakenly equate this positive desire for high standards with a need to make their entry-level courses overly rigorous—for example, with substantial mathematics and science requirements. These act as unnecessary barriers to entry for some students who could be successful in the IT field. Certain jobs, such as those in scientific programming, do require substantial training in calculus and science, but other kinds of IT jobs would benefit more from having their workers receive other kinds of training in problem-solving. Some of the requirements in IT-related undergraduate programs may be a holdover from earlier days, when a scientific programming career was the norm for college graduates in computer science. In any event, computer science and computer engineering entry-level courses sometimes have unusually high attrition levels, which is not in the long-term interest of students, employers, or the departments themselves.

Another problem of the introductory course in most computer science departments is that it is generally devoted entirely to learning the principles of computer programming. Such a course is narrowly focused and technical. It does not give students a good introduction to the nature of the computing field. For example, it does not show the engineering, mathematical, or theoretical aspects of the subject, how computers relate to business and management or to psychology, or how information technology can be applied to a wide range of problems in many fields of endeavor. Many of the scientific and engineering disciplines have developed introductory courses that survey the basic concepts and methods of their field, and the study group believes this would be appropriate for the IT-related disciplines as well. Students need to get, at an earlier stage in their education, a sense of what this subject is all about in order to make better-informed decisions about their studies and their career. The study group heard anecdotes about students who had indicated that they did not want to major in computer science because they perceived that it led to a career working with machines instead of with people. Some did not want to spend all their time involved in the technical problem-solving arcana of programming, but instead wanted to be working on real-world applications. Some students did not like the uncollaborative attitude they had seen among programmers. Courses that better show the human dimension of computing and its applicability would help to address these concerns.

2.5. IT-related departments should increase rather than restrict access to their courses and programs.

Because of the strong need for substantive education in computer science for other curricula (to prepare for IT or IT-enabled jobs), this increased demand may require both new funding from the university and reallocation of departmental funds. There is substantial enrollment pressure on faculty in IT-related departments today. At many schools the size of the undergraduate enrollment is increasing much faster than the size of the faculty or the graduate student population. This leads to large lecture classes, excessive demand on computer facilities, and student-teacher contacts that are stretched thin. Departments are limited in the number of students they can handle without additional resources, and when they become stressed by enrollments, they understandably take action to relieve the stress.

All of these strategies limit student opportunities to train for IT careers. It also means that those students who are admitted into the courses have a certain intellectual profile, which may be good for some IT occupations and less appropriate for others.

2.6. IT-related departments should develop graduate-level programs.

People with strong backgrounds in mathematics, science, engineering, or business have knowledge and skills that will allow them to retrain quickly for IT occupations, such as managers or creators of new technology. There have been surpluses of mathematicians, physicists, biologists, and engineers in recent years. Many of these scientists and engineers are of very high intellectual and technical quality, but are in fields that are unable to provide good careers. Technically oriented graduate programs in computer science, computer engineering, or information science could, with additional resources, accommodate the retraining of people with these skills by repackaging existing courses into a certificate program. Certificate programs that are focused rather than general seem to be particularly attractive to both students and employers. Examples of certificate programs of this kind are human-computer interfaces, bioinformatics, and high-performance computing.

2.7. University practices should be adjusted in order to be more supportive of the education of IT workers.

Better counseling is needed to let students know about opportunities in the IT field, the nature of the work, and the skills required to be successful in the field. This is particularly wanting in two-year colleges and high schools, but may be deficient in many four-year colleges and universities as well.

Existing IT-related departments (typically in computer science, computer engineering, or information science) can do more to provide additional paths to IT careers. This can be achieved, for example, through more flexible entry requirements into majors and by adding minors, cross-disciplinary programs, and certificates. The university administration should be supportive of these efforts in the existing departments.

However, there is a limit to how much any given department can do and still remain manageable in size and focused in mission. With good planning, there can be value in having multiple IT-related departments, each with its own mission, in the same university. This is already common at large universities. Some universities, such as Pennsylvania State, Berkeley, Rensselaer, and Michigan, have kept their existing departments intact and focused on their traditional missions, while at the same time forming new departments or schools to address some other, often interdisciplinary, aspects of information technology.

2.8. New ways are needed to improve the articulation between different levels of educational institutions.

This is a long-standing problem in many fields of higher education, but the IT situation highlights it and argues for new approaches. We have heard many comments about the difficulties that students experience in trying to transfer credits from one program to another as they move through the higher educational system in preparation for an IT career. This occurs at all levels—as a student moves from the vocational to the college preparatory associate degree, from the associate to the final two years of the baccalaureate degree, from one IT-related major at the baccalaureate level to another (management information science to computer science, for example), or from the professional master's degree to the doctorate. These kinds of problems are best addressed by having institutions at a variety of levels work together to set standards and procedures. Because procedures already exist for this kind of system-wide discussion and coordination in state higher educational systems, they need to take a leadership position on these issues and provide examples of best practices that can be followed by the entire U.S. higher educational system.

3. INDUSTRY

3.1. Industry should make data available regarding the demand for IT workers.

In the course of this study, it was almost impossible to obtain current data about industry demand for IT workers. Federal data were out of date and had problems of classification, and most industry data were both firm-specific and proprietary. Without cooperation from industry in supplying information about the kind of personnel they need, it is impossible for suppliers to plan accordingly. It would be useful to have data that meet all of the requirements set out above in the section on recommendations to federal and state governments about data-collecting practices.

3.2. Companies should invest more in entry-level training and the retraining of existing personnel.

Some medium and large-size companies already have extensive training programs for their IT workers. However, some small and mid-size companies do not invest substantially in training their workers, believing that they cannot afford the cost or time of training, or out of fear that they will be training employees who will eventually go to work for their competitors. Some companies that do invest do not invest optimally by planning for training, rather than responding to individual cases in an ad hoc way. In this fast-paced field, where product lines turn over in a matter of two or three years and where knowledge becomes obsolete in about the same length of time, it is critical that the workforce retain outstanding technical and communication skills, as well as industry and business knowledge. Companies should value the training provided by colleges and universities, but should not expect these schools to have produced the perfect employee. Even new college graduates from the strongest universities will not have all the knowledge they need to excel in the workplace. Given the many options in terms of subject, supplier, cost, and length of training available in the marketplace, there is likely to be a training program available to suit any employer need. Companies could broaden the candidate pool by their willingness to carry out more entry-level training, rather than expecting new employees to enter the company with all the requisite skills in place. Industry should also encourage its current employees to increase their skills by providing flexible work schedules, tuition assistance, and opportunities for distance or other kinds of learning experiences.

One of the impediments to more training for workers is that companies fear their training funds will be counterproductive if they train an employee who leaves the company to work for a competitor. A few attempts have been made by a collection of employers in a geographical region interested in the same labor pool to band together and jointly offer training programs for their collective group of employees. Sematech is an example in the semiconductor area. Companies participating in these arrangements have less fear of this migration problem because they believe they will profit as often as they lose under this system, and that all the employers will have access to a more highly qualified labor pool.

3.3. Companies outside of the IT sector need to recognize that information technology may become a core competency for them.

Some members of the study group believe that the Y2K problem is as serious as it is today because many companies outside of the IT sector reduced their IT workforce a few years ago, at the time when many corporations downsized. Companies need to recognize that information technology is essential to their livelihood, even if their main business is not IT products or services. These companies need to keep the quantity and quality of their computer operations at a high level in order to remain competitive. Given the competition for good IT workers and the striking variations in capabilities and productivity among these workers, managers will have to work to make their company a place that is perceived as an attractive place to work by IT workers.

3.4. Industry should work closely with the higher education system to improve education for IT workers.

The higher education system is one of this nation's great strengths, and it needs industry's support to remain vital. In recent years, some companies have de-emphasized their reliance on the higher education system and formed new kinds of training programs, either in-house or purchased from for-profit vendors. Companies gain from having programs that customize the curriculum to their particular needs, but the higher education system also plays an invaluable role in the production of a trained workforce. Individual companies, as well as industry groups, should work closely with colleges and universities to develop a more comprehensive curriculum—one that teaches the foundational skills that are the hallmark of the formal educational system as well as offering current, practical knowledge. Industry should support the formal university program by sponsoring scholarships and internships, providing access to facilities not available at the university, helping to outfit university laboratories, helping the schools with their staff development, having company professionals give lectures and teach courses at the university, and entering into various kinds of programmatic partnerships with the schools.

3.5. Industry should not take actions that in the long run harm the supply system.

Companies should restrain themselves in hiring students before they have completed their degrees, or at least support them to finish the degree as part-time students if they do hire them. This is a way in which companies can both be good citizens and help themselves in the long run. Students who are able to complete their education have learned a set of foundational skills that will make them more effective employees. They will be less likely to become obsolete quickly, and will be better able to learn new skills and knowledge as needed.

Companies should also restrain themselves from hiring away faculty. Unless there is an adequate number of high-quality faculty and enough students completing their doctorates to renew the faculty ranks, the IT community will again have a seed-corn problem and the universities will become progressively less able to train students who will meet industry needs. Industry needs to sacrifice some of the short-term payoffs of hiring faculty and students, seeing them instead as long-term investments in their own future and in the strength of the national IT workforce.

3.6. Companies should hire for diversity and tap aggressively into groups that are under-represented in the IT profession.

This strategy will increase the candidate pool. It will also add diversity to the workforce that can be beneficial to the company in understanding customers, understanding computer applications, and obtaining a diversity of views in the workforce.

4. PROFESSIONAL SOCIETIES

We believe that there is a great opportunity for the professional societies to provide additional, much needed services to the professional community. This may serve not only their members, but the societies themselves by building up their membership rosters.

4.1. The professional societies should provide greater assistance in the retraining and continuing education of IT professionals.

The formal education an IT worker receives in college (and graduate school) provides adequate background preparation for the job for perhaps only two to three years. It is increasingly apparent that IT workers need to be engaged in a continuous process of education, and that it may be necessary to undertake major retraining more often. The professional societies have given some attention to these issues in their continuing education programs. They should take an even more active role in assuring that their members have good opportunities for continuous retraining.

4.2. The professional societies should take a more proactive role in the certification of IT professionals.

As jobs and the requisite skill sets change rapidly in the IT field, it is difficult for any worker to know which of his or her skills is adequate and which need to be brushed up. As the training opportunities multiply, workers are at a loss to know which ones are appropriate for them. If the professional societies can provide certification standards, workers can assess their own skills and seek out appropriate training, and employers can determine if applicants and employees are well qualified to carry out specific IT jobs.

4.3. Professional societies should continue to play a strong role in curriculum development.

For more than thirty years, the computing professional societies have played an important role in developing and publicizing model curricula in IT-related fields. This is one of the most important tasks they can carry out in the future. In developing these curricula, the professional societies should listen to the needs and expectations of employers as well as of suppliers. Given the rapid pace at which information technology is being developed, and at which knowledge becomes obsolete, it is important to develop model curricula that are designed for change. What is needed are curricula that can accommodate small modifications on a regular basis, rather than curricula that are expected to stand without revision for many years. One place where the professional societies can be especially helpful is in developing model curricula for associate degree programs, and in particular in setting minimal standards and procedures for a two-year college that wants to adopt a curriculum developed by one of the technology vendors. Attention should also be given to curricula for professional master's programs and to post-baccalaureate certificate programs in specific technical areas such as bioinformatics or network administration.

4.4. The professional societies should take considerably greater interest in non-degree programs that train IT professionals.

Most model curricula and accreditation of IT training offered by the professional societies are directed at formal degree programs offered by traditional colleges and universities. The fastest growing segment of IT training, however, is that of the non-degree programs offered by two- and four-year colleges and universities, as well as by for-profit training companies, individual consultants, and the companies themselves. These include short courses, certificate programs, distance learning programs, and other kinds of training. Because there are currently no guidelines, these are *caveat emptor* purchases, both for the students themselves (who are often members of these professional societies) and for the companies that often pay for their workers to attend. The professional societies could take a major role in setting standards and accrediting programs. Formal continuing professional education programs of the type used in K-12 teacher training and in the medical and legal professions may also be helpful.

4.5. The various IT professional societies should communicate, cooperate, and collaborate more with one another on issues of worker supply and demand.

As the IT field broadens, the number of professional societies dedicated to information technology grows. There are at least twenty IT-related disciplines taught in U.S. universities today. Many of them have at least one professional society representing them. Many of these societies are focused on a particular aspect of information technology. Several societies, seemingly independently of one another, were already working on issues related to IT workers and training programs when this study began. There is no single overarching society for the entire IT field, nor it does appear that one will be formed anytime soon. Absent such a society, it is important that the existing societies communicate with one another and collaborate, or at least cooperate, on study groups, model curricula, and accreditation. It may even be desirable to form a loose federation of IT-related societies for this purpose. The Computing Research Association has taken first, preliminary steps in this direction through its annual computing leadership summit.

5. INDIVIDUALS

5.1. Workers should recognize that they must take responsibility for remaining individually competitive.

The United States is a free and mostly unregulated market in which companies do not hesitate to lay off even good workers if they do not have the currently needed skills. This means that employees must plan to be flexible and not view as a failure a need to change jobs or return for further education in the middle of their career. Workers should be careful to choose jobs so that they broaden and update their skills, and they should be open to learning.

5.2. Individuals must commit themselves to life-long learning in order to remain technically current and competitive.

There are many ways in which an individual IT worker can obtain this training, such as college and university courses, lectures, seminars, and self-study. The individual worker should take advantage of the opportunities offered by the employer and should also personally seek out other opportunities. IT workers who become complacent about their knowledge and skills can become obsolescent in as little as two years. The professional societies can be a good source of information about what knowledge and skills are in demand, and they may even be able to provide them or point to reliable providers.

5.3. Individuals should do their part to see that people with appropriate skills enter the IT workforce.

People choose an occupation in large part because of personal contacts they have had—the strong teacher, the knowledgeable and fair supervisor, the caring colleague. Individuals can attract people with good skills to IT careers by encouraging IT as a career, by serving as a mentor to students or less experienced employees, by advising people on their training and career decisions, and by serving as a good role model.

5.4. Individuals should help to build up the IT profession through its professional organizations.

The IT profession is much stronger because of its professional societies, its university training programs, and the public and private organizations that look out for its well-being. Members of the profession should be good citizens by offering to serve on national committees, review proposals, volunteer to participate in professional society activities, lecture or teach and the local college, and do other volunteer and paid efforts that strengthen these professional organizations.

Box 10-1: Recommendations

Federal and State Governments

1.1. Data-collection practices must be improved.

1.2. A new system for tracking the demand for and supply of IT workers should be created.

1.3. Data collected must be comprehensive to be useful for policy deliberations.

1.4. The Standard Occupational Classification (SOC) categories for information technology occupations need to be reviewed and refreshed on a regular basis.

1.5. Federal and state governments, with industry involvement, should improve IT-related mechanisms at the K-12 educational levels and keep them current. Counseling, teacher training, curricula, and computing facilities all need improvement relative to information technology.

1.6. The federal government, and especially state governments, should help to strengthen traditional higher educational programs in IT-related areas.

1.7. Government can help faculty and educational staff adapt to the new demand for IT-trained students.

1.8. Government should help to attract more students into graduate programs in IT-related disciplines..

1.9. Government should help faculty and staff cope with the greatly increased demand in the IT area.

1.10. The federal government, and NSF in particular, must be vigilant and prevent a seed-corn problem in IT-related disciplines.

1.11. Federal and state governments must enhance the research climate in the universities.

1.12. Federal and state governments should actively encourage universities and industry to form a variety of partnerships to train the IT workforce.

1.13. The government should encourage the development of programs in academia and industry that attract underrepresented groups to IT careers.

1.14. Special efforts should be made to utilize the skills of older workers.

Higher Education

2.1. Colleges and universities should keep their focus on providing strong basic education.

2.2. Universities must recognize that there is a fundamental IT-related shift occurring in the economy and in most professions, and that they must reallocate resources for better and more extensive training in this area.

2.3. Higher education should provide faculty support to revise their curricula to provide more and better paths in the training of IT workers, as well as to provide better IT education for all students.

2.4. Faculty in IT-related disciplines need to rethink their introductory under graduate courses.

2.5 IT-related departments should increase rather than restrict access to their courses and programs.

2.6. IT-related departments should develop graduate-level programs.

2.7. University practices should be adjusted in order to be more supportive of the education of IT workers.

2.8. New ways are needed to improve the articulation between different levels of educational institutions.

Industry

3.1. Industry should make data available regarding the demand for IT workers.

3.2. Companies should invest more in entry-level training and the retraining of existing personnel.

3.3. Companies outside of the IT sector need to recognize that information technology may become a core competency for them.

3.4. Industry should work closely with the higher education system to improve education for IT workers.

3.5 Industry should not take actions that in the long run harm the supply system.

3.6 Companies should hire for diversity and tap aggressively into groups that are underrepresented in the IT profession.

Professional Societies

4.1 The professional societies should provide greater assistance in the retraining and continuing education of IT professionals.

4.2. The professional societies should take a more proactive role in the certification of IT professionals.

4.3 Professional societies should continue to play a strong role in curriculum development.

4.4. The professional societies should take considerably greater interest in non-degree programs that train IT professionals.

4.5. The various IT professional societies should communicate, cooperate, and collaborate more with one another on issues of worker supply and demand.

Individuals

5.1. Workers should recognize that they must take responsibility for remaining individually competitive.

5.2. Individuals must commit themselves to life-long learning in order to remain technically current and competitive.

5.3. Individuals should do their part to see that people with appropriate skills enter the IT workforce.

5.4. Individuals should help to build up the IT profession through its professional organizations.

Source: Computing Research Association, Intersociety Study Group on Information Technology Workers, April 1999.

Appendix A. Methodology

In the course of this study, the study group has tried to be as objective as possible in its approach. The Computing Research Association (CRA) and the other professional societies organizing this study did not take a position on the reports prepared by the Information Technology Association of America (ITAA) and the Department of Commerce, or on the H-1B legislation.[112] Prior to the study, some of our academic members reported rapidly increasing undergraduate enrollments in computer science and similar rises in information technology (IT) recruitment on campus; and some of our industrial members had mentioned their difficulties in hiring workers. But we did not know whether these were isolated or general phenomena; and we certainly had not reached any conclusions or recommendations in advance of the study. We endeavored to hear as many viewpoints as time would permit. We were well positioned to do so because the societies participating in the study—CRA and its five affiliates—represent approximately 100,000 U.S. computing professionals; and because CRA is one of the few computing organizations that includes both academic and industrial organizations as members. We tried to broaden the perspective further by:

1. Consulting with government officials and staff (from the National Science Foundation, DARPA, the White House Office of Science and Technology Policy, the U.S. General Accounting Office, and Congress) at the beginning of the study to learn what issues related to the worker issue were of most concern to them.

[112] Four of the five affiliated societies had no programmatic contact with these issues. The situation of the remaining collaborator, the IEEE Computer Society, is more complicated. The parent organization of the Computer Society, the Institute of Electrical and Electronics Engineers, is a worldwide organization that operates a national U.S. professional organization in Washington, DC, known as the IEEE-USA. The IEEE-USA was vocally opposed to the H-1B legislation. However, the Computer Society did not take a position or an active role in the lobbying efforts of the IEEE-USA and had no control over them. In its major publication, *Computer*, the Computer Society ran guest editorials and accepted letters to the editor that were fairly evenly split between pro and con on the H-1B legislation. CRA regards the Computer Society as a neutral organization with respect to the IT worker legislation, although the IEEE-USA is clearly not neutral on this issue.

2. Forming a study group of twenty-three professionals, each of whom brought some particular expertise such as:

a. knowledge of supply issues (e.g., specialists on K-12, two-year college, four-year college, graduate, and continuing education);

b. knowledge of demand issues (e.g., college recruiters, managers of research laboratories, workers in non-IT industries that needed IT workers); and

c. knowledge of contextual factors (e.g., people familiar with past IT worker shortages, demographers, and social scientists familiar with software production and use).

3. Engaging consultants who had knowledge of data collection and analysis in science and technology, and labor economists familiar with IT work.

4. Collecting information from many organizations, such as the IEEE-USA and other professional societies that represent IT occupations, such as the Association of Information Science and the Society for Information Management.

5. Having the draft report reviewed by more than fifty people from many different sectors of U.S. society, including people who took various positions on the ITAA and Commerce reports and on the H1-B visa debate.

As CRA is an organization representing research scientists, one way in which we tried to be objective was to take a "scientific" approach to this study by letting the data drive the analysis wherever possible. Neither time (8 months) nor budget allowed us to collect new data. However, we searched extensively to locate and gain access to existing data sets that we believed might have a bearing on this study. Our list of data sources is described in chapter 9. NSF generously ran some new cross-tabulations for us on some of their existing data sets. For each data study, we reviewed the organizations and individuals surveyed, the categories in which data responses were reported, the sample size, and other factors to determine the general reliability of the study. We compared and contrasted studies and paid particular attention where studies gave conflicting reports.

We were only modestly successful in this quantitative approach. We were frequently frustrated by how old the data were, how poorly the occupational categories used in surveys fit with the current situation, and how many questions were simply not addressed by any existing data. To fully address the worker shortage issues, we often had to go beyond quantitative evidence and rely on qualitative evidence and expert judgment. Where we did this, we were particularly careful to obtain extensive review. We did not employ any formal method to reduce the many opinions we heard to a general consensus. Instead, we simply weighed all the evidence and used our long experience in the field to make our best judgments.

Appendix B. Related Studies

In the course of this study, we had access to the two reports prepared by the Information Technology Association of America (ITAA), the Department of Commerce report, the U.S. General Accounting Office (GEO) report, the GAO's House testimony, a National Research Council (NRC) report on computer professionals, a variety of statistical information collected by the federal government and private organizations, and many other materials produced by the private sector. These sources are cited in footnotes.[113] It was our intention in this study to take a fresh look at the evidence and conclusions presented in these studies. We have considered them and the issues they discuss in terms of general questions about information technology in the national economy.

The ITAA, Commerce, and GAO studies are basic to understanding the current debate, and they are discussed in some detail in chapter 1. In addition, there are three other reports that have not received the public attention they deserve. The Jerome Levy Economics Institute of Bard College convened a symposium in June 1998 entitled, "Is There a Shortage of Information Technology Workers?" The proceedings of this symposium present measured, succinct statements by ITAA, Commerce, and GAO, as well as by other leading labor economists and policy analysts.[114] The second report is a 1993 study on computing professionals prepared under the auspices of the National Research Council (NRC).[115] Some of

[113] The study group did not have an opportunity to consider three recent reports sponsored by the Sloan Foundation and the United Engineering Foundation as part of an IT Workforce Data Project. See Richard Ellis and B. Lindsay Lowell, "Core Occupations of the U.S. Information Technology Workforce," January 1999; "The Production of U.S. Degrees in Information Technology Disciplines," January 1999; and "Foreign-Origin Persons in the U.S. Information Technology Workforce," March 1999. A final report will assess indicators of demand for people with IT skills. [e-mail: ellis@cvns.net]

[114] "Is There a Shortage of Information Technology Workers?" Symposium Proceedings, The Jerome Levy Economics Institute of Bard College, June 12, 1998.

[115] *Computing Professionals—Changing Needs for the 1990's*, National Research Council, National Academy Press, 1993.

the conclusions seem wrong in hindsight: a slowing demand for computing professionals in general and high-level researchers, and the adequacy of supply. However, the NRC report shares many conclusions with this study: the importance of information technology to the national economy, the opportunity losses created by worker shortages, the serious lack of data needed to reach conclusions, the rapid change occurring in desired skill sets of IT workers, the need for increased efforts by the universities, and the need to improve and increase continuing education.

Third, we point the interested reader to a paper on "Skill Mismatches and Worker Shortages" prepared by Burt Barnow, John Trutko, and Robert Lerman on behalf of the U.S. Department of Labor.[116] The study group has relied heavily on their analysis of federal data, although in this report it has, in some cases, been presented in a different form. We have also relied on their economic analysis of indicators and responses of workers and employers in the face of labor shortages, although we have tried to go beyond their analysis by giving detailed information about how their mechanisms work in the IT labor market.

[116] Burt S. Barnow, John Trutko, and Robert Lerman, "Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses," submitted by The Urban Institute to the Office of the Assistant Secretary for Policy, U.S. Department of Labor, draft final report, February 25, 1998.

Appendix C. About the Authors and the Sponsoring Organization

The study was conceived and directed by the Computing Research Association (CRA), a nonprofit educational organization located in Washington, DC, whose mission is to promote research and advanced education in computing. Its members are university departments of computer science and computer engineering, as well as laboratories and centers in industry and government that conduct research in computing. The study was carried out in collaboration with five other major computing professional societies that are affiliates of CRA: the American Association for Artificial Intelligence, the Association for Computing Machinery, the IEEE Computer Society, the Society for Industrial and Applied Mathematics, and the Usenix Association.

The principal authors of the study are Peter Freeman and William Aspray. Peter Freeman (Ph.D., computer science, Carnegie Mellon University) is Dean and Professor in the College of Computing at Georgia Institute of Technology. He is a long-standing member of CRA's Board of Directors and former chair of its Government Affairs Committee. William Aspray (M.A. mathematics, Wesleyan University; Ph.D., history of science, University of Wisconsin) is the Executive Director of the Computing Research Association.

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Appendix F. External Reviewers

Early drafts of the report were reviewed by the 23 members of the study group and many of the 31 members of the CRA Board of Directors. In addition, the following external reviewers provided comments:

Eleanor Babco	Commission on Professionals in Science and Technology
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Eileen Collins	National Science Foundation
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