

The New Division of Labor

How Computers are Creating the Next Job Market

BY FRANK LEVY
AND RICHARD MURNANE

Computers – can't live with 'em, can't live without 'em. Yes, I'm paraphrasing a hoary joke that wasn't very funny in the first place.

But it really does apply to the machines that both make us rich and drive us mad. ¶ Frank Levy and Richard Murnane, economists at MIT and Harvard respectively, offer a cool analysis of a hotly debated issue: how to reap the benefits of computers in the workplace without paying a heavy price in terms of



displaced workers. And the prognosis, they suggest, is guardedly optimistic. Coping with the social consequences of “the hollowing out of the occupational distribution,” they argue, will require job training that focuses on what computers do least well – expert communication and complex thinking.

— Peter Passell

*Published by Princeton University Press. All rights reserved.

In November 1962, Boeing

launched the 727, a 131-passenger jetliner designed to operate out of small airports with short runways. The rollout completed an 81-month development process during which more than 5,000 engineers worked with thousands of pounds of blueprints to design an aircraft that included more than 100,000 parts. The airplane's complexity meant that no one person could guarantee the blueprints' internal consistency, and so the second step in the design process was the construction of a full-scale model to ensure that the components fit – that proper space had been left for the aircraft's seats, hydraulic lines, air-conditioning ducts and other components.

When the model was completed and the blueprints had been corrected, design engineers translated blueprint specifications into settings for stamping presses, turning lathes and the other machine tools that would fabricate the 727's parts. The translation resulted in many small errors and the parts often fit imperfectly. Assembly workers had to adjust the parts by hand, using metal shims to fill in small gaps. A manager familiar with the process estimated that a 727 weighing 44 tons typically contained a half-ton of shims.

In April 1994 Boeing rolled out the 777, a 305-passenger plane designed to fly up to 6,000 miles. Although much larger and more complex than the 727, the 777's development cycle was shorter by 29 months. The explanation was no secret: the 777 was the first commercial jet to be completely designed using computers. Employing CATIA, computer-assisted design and manufacturing software developed by the French company Dassault Systèmes, engineers created components on computer screens rather than on paper. The software's power was its ability to integrate

individual views into three dimensions. The virtual model substituted for a physical mock-up in checking plans for internal consistency. Once engineers had corrected the plans, CATIA produced the digital settings for the computer numerical controlled (CNC) machine tools that would fabricate the 777's parts.

Boeing purchased the CATIA system as part of an effort to pursue several competitive strategies. One was to compete better by increasing design speed. Being first to market is particularly important in civilian aircraft, where two large producers – Boeing and Airbus – vie for a limited number of orders. Boeing's adoption of CATIA eliminated the need for mock-up models and reduced the time required to correct plans and to set up machine tools.

A second competitive strategy facilitated by CATIA was improved product quality. The digital settings that CATIA produced for CNC machine tools made it possible to produce parts that fit together well, so the 777's assembly required far fewer hand adjustments and shims.



CATIA also made it possible for Boeing to compete by configuring to customers' specifications without long design delays. Then, too, CATIA and other software innovations facilitated the outsourcing of blue-collar manufacturing work. Once CATIA produced the digital machine tool settings, the machine tools themselves could be located anywhere since Boeing knew the parts would fit when brought to a common assembly point.

Boeing located production in Italy, the United Kingdom, Japan and other countries, in part to attract foreign customers and in part to reduce production costs. In retailing, a similar conquering of geography occurs as firms like Amazon.com and Land's End use single Web sites to reach widely dispersed customers and use computerized shipping to deliver orders in acceptably short times.

None of these goals is new. Fifty years ago,

Boeing wanted to bring high-quality planes to market as soon as possible and to tailor specifications to customers' preferences. What was new – what computers had changed – was the cost. Fifty years ago, bringing aircraft to market sooner without compromising quality would have involved paying vast amounts of overtime. The adoption of computer-based design tools and computer-driven production tools dramatically lowered the cost of achieving these goals.

The Boeing-CATIA story illustrates a final computer-supported strategy: the creation of new, information-intensive products, including CATIA itself. CATIA, CDs, cell phones, DVDs, global positioning devices, the modern echocardiograph machine, the Eurex Trading network, complex financial derivatives, and the PalmPilot are all successful products made possible by computers.



WHY JOBS CHANGE

As the Boeing-CATIA example suggests, computers change work through a three-step process. The first step occurred when Boeing purchased CATIA to pursue competitive strategies that were impractical without computers. To take advantage of CATIA's capabilities, Boeing next had to reorganize work, using computers to substitute for humans in carrying out some tasks and to complement humans in carrying out others. In the final step, the reorganization of work changed both Boeing's job mix and the skills needed to do many jobs. Engineers now had to create designs on computer screens rather than drafting boards. The labor to build a full-scale mock-up was no longer needed and the labor spent hand-fitting parts was sharply reduced. Some jobs that had been previously located in the United States were moved offshore.

The same three-step process characterizes almost every new application of computers.

Firms adopt computers to gain a particular competitive advantage. Realizing computers' potential requires reorganizing work. As computers proliferate in the workplace, the jobs they create, destroy and change are the by-product of this work reorganization. Since computers are present in a large and growing number of American workplaces, they are catalyzing dramatic change in the nature of work.

FOUR WAYS TO THINK ABOUT WORK

When we ask how computers are changing work, we have four specifics in mind.

Employment. With all the prophecies that computers would create mass unemployment, why didn't it happen?

The economy's mix of jobs. As computers have substituted for humans in carrying out some tasks and complemented humans in tackling others, what kinds of jobs have grown in importance, and what kinds of jobs have declined?

Wages. What are the wage trends for different kinds of workers, and what do these trends tell us about the changing content of work?

Worker skills. Which skills are of rising importance in the economy and which skills face diminishing demand? The answer to this question involves changes in the economy's mix of jobs but also the changing nature of work within jobs.

Employment

The economy is still struggling to extricate itself from the post-bubble recession, but the current unemployment rate is nothing like the mass unemployment expressed in the automation scares of the 1960s. In any event,

Had computers created large-scale unemployment, we should have seen the first signs by the end of the 1960s. In fact, the opposite occurred.

by focusing on the unemployment rate, we will miss the economy's strong job-creation performance as computer use soared.

In the mid-1960s, mainframe computers were a commercial reality, and special-purpose computers – for example, computers that control machine tools – were on the horizon. Had computers created large-scale unemployment, we should have seen the first signs by the end of the 1960s. In fact, the opposite occurred.

For much of the 1970s and 1980s, the labor force grew explosively as the baby boomers matured and women of all ages moved into paid work. The fast growth in the number of potential workers meant that the number of jobs had to grow rapidly to keep unemployment from rising. In 1969, a boom year, unemployment stood at 3.5 percent. In 2000, another boom year, unemployment stood at 4.0 percent. In the intervening 31 years, total employment grew from 83 million to 135 million – clearly not the picture once feared.

In Nobel Prize-winner Herbert Simon's 1960 essay, "The Corporation: Will It Be Managed by Machines?" Simon explained why predictions of mass unemployment would prove wrong. Borrowing from international trade theory, Simon invoked David Ricardo's historic principle of "comparative advantage." Simon began from the premise that society can always find uses for additional output (consider today's unfulfilled demand for health care). Under this premise, computers and humans will both be used in producing this output, each in tasks for which they have a comparative advantage. As Simon wrote:

If computers are a thousand times faster than bookkeepers in doing arithmetic, but only one hundred times faster than stenographers in taking dictation, we shall expect the number of bookkeepers per thousand employees to decrease but the number of stenographers to increase. Similarly, if computers are a hundred times faster than executives in making investment decisions, but only ten times faster in handling employee grievances (the quality of the decisions being held constant), then computers will be employed in making investment decisions, while executives will be employed in handling grievances.

Note that in Simon's examples (as in Ricardo's original formulation), computers are more efficient than humans in both tasks, but employing humans is still worthwhile in tasks in which they have a comparative (that is, relative) advantage. As we know, our current situation is not this extreme since humans are more efficient than computers in understanding speech, interpreting visual images and in a host of other activities requiring recognition of complex patterns. At the same time, Simon does not rule out that the adoption of computers may cause painful adjustments, or that workers displaced by computers may regain employment only at lower wages – at least in the short run.

The story Simon describes has played out with many technologies. When the combine harvester came into widespread use in the 1920s, it displaced manual labor and created substantial rural unemployment. Over the longer run, most farm workers were reemployed through either of two channels. In the

first, greater efficiency in agriculture meant that farm products could be sold at lower prices, so consumers could increase purchases. Workers were rehired to help produce the larger levels of output now demanded by consumers.

In the past 20 years, this channel has characterized “back-office” jobs in the securities industry. Consider the entry-level accountants who keep the books for mutual funds and compute the net asset value per share that appears in daily newspaper stock tables. Over two decades, the computerization of their job has allowed the average accountant to keep records for four mutual funds instead of one or two. Had the number of funds stayed constant, the accountants’ greater productivity would have meant fewer accounting jobs. But over the same period, the number of mutual funds expanded from 500 to 5,000 and the number of fund accountants significantly increased. The growth in the number of mutual funds stemmed, in part, from the decline in the cost of running a mutual fund as computers lowered the costs of record keeping, trade execution and other back-office functions.

The second, more important channel of re-employment was the movement of displaced workers into other, expanding industries. In the first half of the 20th century, large numbers of displaced agricultural workers moved into manufacturing. Similarly, beginning in the 1970s, displaced manufacturing workers moved into service jobs. These moves can be painful and can involve significant cuts in pay and benefits, but they avoid long-term unemployment.

With both channels, the economy produces more goods and services per person. Thus, the mechanical harvester allowed the same volume of crops to be produced with fewer farm laborers. Depending on demand,

the displaced laborers produce either additional farm output or additional output in the industries to which they moved.

This additional output, representing income for someone, is no economist’s fantasy. In 1947, the median U.S. family income stood at \$20,400 (in 2001 dollars). By 1964, it had risen to \$31,773. The growing purchasing power largely reflected increased output per worker stemming from technological improvements and a more educated workforce.

Today, median family income stands at about \$51,000, and a significant fraction of recent gains has been spent on computer-related consumer goods: cell phones, advanced medical treatments, CDs, DVDs and so on. These purchases, in turn, increased employment in those occupations in which labor had a comparative advantage.

In sum, plenty of evidence supports Simon’s argument that computerized work does not lead to mass unemployment. But Simon also made clear that computerization could sharply alter the economy’s mix of jobs.

The Mix of Jobs

How do computers affect the economy’s job mix? Most predictions have fallen into one of two categories. The first is that computers will do low-level, routine work, so that people have to move into higher skilled work to survive. The second is that computers will largely do high-level work, leaving most people no alternative but menial jobs.

Peter Drucker, the management theorist, belongs in the first category. In Drucker’s mind, computerization subsumes routine work, and so the real danger is a shortage of trained managers to direct what computers should do. By contrast, Jeremy Rifkin, the author of *The End of Work*, argues that the economy’s requirements for high-level

knowledge workers can never compensate for the number of jobs computers will eliminate. The result will be a large concentration of workers in low-level, dead-end jobs. Apparent support for this prediction comes from the U.S. Bureau of Labor Statistics, which projects that food preparation and service workers, who require little training, will gain more jobs between 2000 to 2010 than any other occupation.

In his 1960 essay, Herbert Simon made a set of predictions about the job mix in a typical corporation in 1985. Simon's predictions were closer to Drucker's than to Rifkin's, but they were more nuanced.

Blue-collar workers: "There will be a few vestigial 'workmen' – probably a smaller part of the total labor force than today – who will be part of in-line production, primarily doing tasks requiring relatively flexible eye-brain-hand coordination."

Machine maintenance workers (i.e., technicians): "There will be a substantial number of men whose task it is to keep the system operating by preventative and remedial maintenance."

Clerical workers: "The departments of a company concerned with major clerical functions – accounting, processing of customers' orders, inventory and production control, purchasing and the like – will have reached an even higher level of automation than most factories."

Salespeople: "If we think that buying decisions are not going to be made much more



Selling will account for a larger fraction of total employment."

objectively than they have in the past, then we might conclude the automation of the salesman's role will proceed less rapidly than the automation of many other jobs. If so, selling will account for a larger fraction of total employment."

Managers: "There will be a substantial number of men at professional levels, responsible for the design of product, for the design of productive process and for general management. We have still not faced the question of how far automation will go in these areas, and hence we cannot say very firmly whether such occupations will be a larger or smaller part of the whole."

Simon's predictions, made in 1960, run counter to predictions made by business analysts in the 1990s. Simon's emphasis on managers goes against the precepts of re-engineering, in which information technology eliminates layers of managers. His qualified emphasis on salespeople runs counter to predictions that e-commerce will dramatically reduce their numbers.

Were Simon's predictions accurate? Consider first the 1969 occupational structure for

adult workers. The U.S. Census Bureau classifies workers into roughly 400 occupational titles – everything from funeral directors to administrators in education and related fields. The chart below groups the detailed occupational titles into seven broad categories arrayed from left to right in order of increasing average earnings.

Professional occupations include teachers, ministers, doctors, engineers and other white-collar jobs typically requiring college or postcollege education. Blue-collar workers include skilled craftsmen, assembly line workers, day laborers and similar workers, most of whom work in industrial settings and have not completed college. Service workers include janitors, cafeteria servers and waiters, police officers, firefighters, child-care workers and others who deal with people face to face; many of these jobs do not require a college degree (Police officers are now an exception in many jurisdictions, but were not so in 1969).

The variety of occupations in each category blurs the implications of the category's average earnings. Service workers *on average* earn less than blue-collar workers, but the highest paid service workers – police officers

and firefighters – earn more than many blue-collar workers. Nonetheless, the chart gives a reasonable overview of the occupational structure.

The chart on page 69 shows how these occupational groupings changed in relative size between 1969 and 1999, a period in which computers of all kinds permeated the economy. (We chose 1999 as the end point of our comparison in order to compare the peaks of two business cycles.)

- Service workers grew modestly from 11.6 percent of all workers in 1969 to 13.9 percent in 1999.

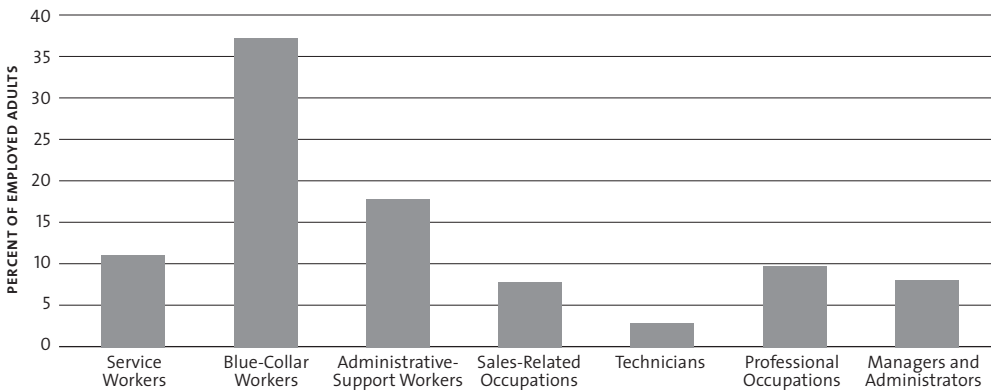
- Blue-collar workers and administrative-support workers both declined. Together, these two groups employed 56 percent of all adult workers in 1969, falling to 39 percent of adult workers in 1999.

- Sales-related occupations ranging from McDonald's order takers to stockbrokers grew from 8 percent to 12 percent of all adults.

- Technicians increased from 4.2 percent to 5.4 percent of all adult workers.

- Professional occupations – engineers, teachers, scientists, lawyers – increased from 10 percent to 13 percent.

THE ADULT OCCUPATIONAL DISTRIBUTION, 1969



SOURCE: Authors' tabulations of data from the March 1970 Current Population Survey.

- Managers and administrators increased from 8 to 14 percent.

This hollowing out of the occupational structure is broadly consistent with Simon’s predictions, including his expectation of more face-to-face interaction. With one exception, it is also consistent with Drucker’s view that growth would be in jobs requiring more education. The exception is the modest growth of service workers at the bottom of the pay distribution.

To see why trends in service workers are difficult to predict, consider the idea that computers are best at routine jobs. In casual conversation, a security guard has a routine job: he or she walks the same beat every night looking for suspicious activity. But from a cognitive perspective, a security guard’s job is exceedingly complex. The core of the job – identifying suspicious activity – begins with the perception of large quantities of visual and aural information. This information must be processed using pattern recognition that requires substantial contextual knowledge. In casual conversation, “routine” means “repetitive.” In software terms, however, “routine” means “expressible in rules.” Determin-

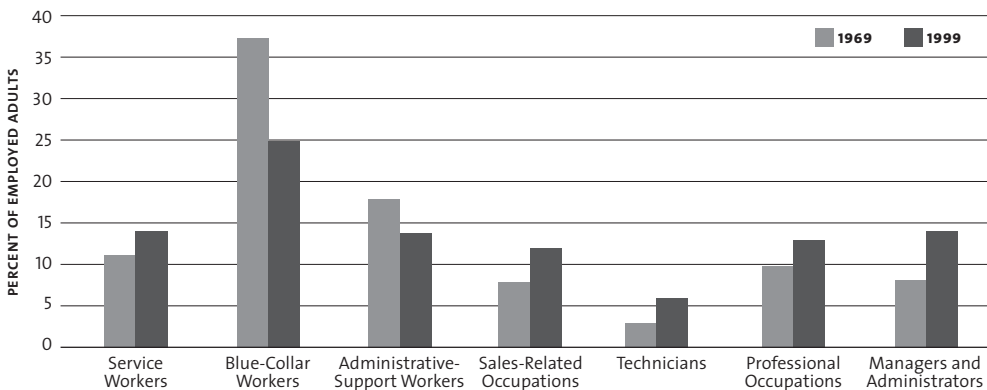
ing whether a person is a potential burglar or a worker staying late is not easily encoded in rules.

A security guard is not paid well because most humans can do the job. But that does not mean the job is easy to program. The distinction between “easy for humans to do” and “easy to program computers to do” helps to explain why routine service workers – cafeteria workers, janitors – have not been replaced by computers, and why the fraction of adults in service work has grown.

More generally, the theory implicit in Simon’s 1960 essay provides a coherent story about why occupations changed as they did:

- The growing number of service workers reflects the inability to describe human optical recognition and many physical movements in sets of rules.
- The growth in sales occupations (fast-food clerks through bond traders) stems in part from the way that an increased flow of new products – driven by computers – increases the need for selling, and in part from the inability of rules to describe the exchange of complex information that salesmanship requires.

THE ADULT OCCUPATIONAL DISTRIBUTION, 1969 AND 1999



SOURCE: Authors’ tabulations of data from the March 1970 and March 2000 Current Population Surveys.



- The growth in the professional, managerial and technical occupation grouping reflects the inability to express high-end cognitive activities in rules: formulating and solving new problems, exercising good judgment in the face of uncertainty, creating new products and services.

- In contrast, many blue-collar and administrative-support jobs can be described in rules, and this accounts in large part for the decline in these two categories through both direct substitution and computer-assisted outsourcing.

As a result, the number of menial jobs is growing, but the general shift of occupations is toward higher-end jobs. While computers are not responsible for all of these changes, they do play a major role in bringing them about.

Before leaving this picture, we have one loose end to consider – the Bureau of Labor Statistics projection that food preparation and service workers will be the occupation with the largest job growth over the next decade. How can this projection square with the general shift of occupations toward

higher skilled jobs?

In the year 2000, there were more food preparers and servers in the economy (about 2.2 million) than there were lawyers (681,000), doctors (598,000) or electrical engineers (450,000). But these head-to-head comparisons tell us little since food preparation and service workers are counted under one occupational title while jobs requiring significant education tend to be divided into many occupations (e.g., electrical engineering is one of 16 major engineering occupations classified in BLS statistics).

The shift that Jeremy Rifkin feared, a “de-skilled” occupational structure, requires that the *total* number of low-skilled jobs increases more than the *total* number of higher skilled jobs. These totals are the kind of occupational categories displayed in the chart on page 69, where food-preparation and service workers are included in service occupations. Once we move from individual job titles to occupational categories, the evidence of de-skilling disappears. Between 1969 and 1999, employment in service jobs grew from 11.6 percent to 13.9 percent of the adult workforce. But

managers, administrators, professional workers and technicians taken together – the highest paid categories – grew from 23 percent to 33 percent.

The Distribution of Wages

In a healthy economy, demands for different kinds of workers are changing all the time – and changing so quickly that it is common for specific kinds of workers to find themselves in shortage or surplus. In the labor market, as in any other competitive market, the best indicators of shortages and surpluses are changes in prices – in this case, wages. When workers with particular attributes are in surplus, their real wages (net of inflation) fall. Real wages rise for workers in shortage.

For the period we are examining, the best wage data comes from the decennial U.S. Census and its companion survey, the monthly Current Population Survey. The charts on page 71 and 72 show trends over the period 1973 - 2001 in the average wages of male and female workers with different educational attainments.

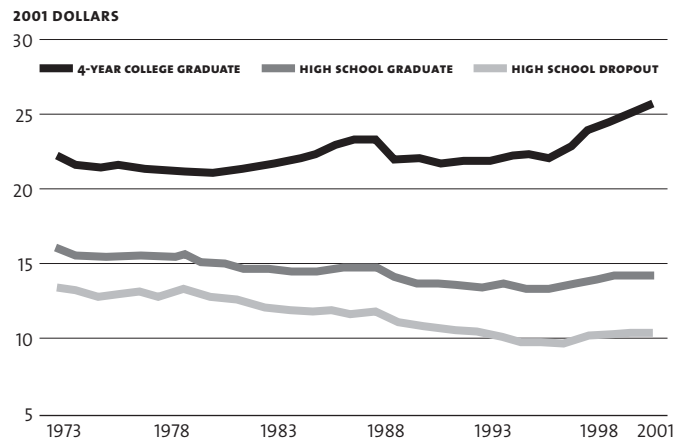
In 1996, the average real wage of male college graduates was almost identical to its value in 1973, an indication that demand kept up with the supply of college-educated workers. Then, in the strong economy of the late 1990s, the real wage of male college graduates grew markedly. By contrast, the average real wage of male high school graduates fell by almost \$3 per hour between 1973 and 1996, and the average wage of male dropouts fell by almost \$4 per hour during this period. While the strong economy of the late 1990s allowed these groups to recover some part of the earn-

ings decline, wages in 2001 were still markedly below 1973 levels for these groups.

The pattern of wage stability and recent wage growth among college graduates, along with long-run wage decline among high school graduates, could have come from changes in the demand for workers with different educational attainments or from changes in their supply. The data points to changes in demand.

During this period, the number of male college graduates was growing faster than the number of male high school graduates and dropouts. Had demand been stable, the fast-

REAL HOURLY WAGE TRENDS FOR MALES 1973 – 2001, BY EDUCATION



SOURCE: Data from Current Population Surveys as reported on the Economic Policy Institute Web site.

er growing group would have experienced declining wages.

That, of course, is not what happened – real wages of male college graduates rose in the two decades after 1980. The changing occupational structure was creating demand for college graduates that outstripped their fast-growing supply. Applying the same logic, the real wages of male high school graduates and male dropouts were falling because demand for these workers was growing even

more slowly than their slow-growing supply.

Women's wages tell a broadly similar story. The number of employed female college graduates grew faster than the number of employed female high school graduates and dropouts. Yet as shown below, the average wage of female college graduates increased quite sharply while the average wage of female high school graduates and dropouts did not grow at all.

We are beginning to fill in the blanks about how computers are changing work.

ing them to jobs that no longer pay enough to support families.

Worker Skills and the New Nature of Work

Today, virtually all public schools operate under mandates to prepare all students to master valued skills. By the same token, corporations spend an average of \$800 per employee on training each year. Much of this effort is devoted to preparing people to work productively in the computerized workplace. If the

effort is to make sense, the nation needs to understand what tasks humans will perform at work and the skills they will need to carry out these tasks effectively.

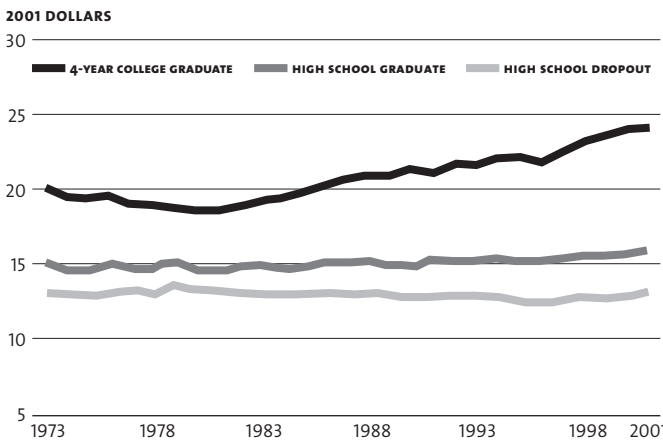
We already have some answers. Computers have a comparative advantage in carrying out tasks requiring the execution of rules, but people have the advantage in recognizing complex patterns. Complex pattern recognition is critical in two quite different kinds of tasks – optical recognition and physical movement (security guards, etc.), and tasks involving higher order cognitive skills. We can usefully divide these

higher order tasks into two broad groups.

The first are tasks that involve solving new problems – problems that cannot be solved by applying well-understood rules. The second consist of tasks that require explanation, negotiation, persuasion and other forms of intense human interaction. We will call these two sets of tasks, respectively, tasks requiring expert thinking and tasks requiring complex communication.

In joint work with David Autor of MIT, we have argued that tasks requiring expert thinking and complex communication are two of

REAL HOURLY WAGE TRENDS FOR FEMALES 1973 – 2001, BY EDUCATION



SOURCE: Data from Current Population Surveys as reported on the Economic Policy Institute Web site.

On the demand side of the labor market, the share of menial jobs has increased modestly, but the largest job growth has been in occupations requiring significant education. On the supply side, the number of college graduates has been growing faster than the number of high school graduates and dropouts. Yet the rising wages of college graduates indicate demand is outstripping their supply. Conversely, the fact that the wages of male high school graduates and dropouts are declining despite the slow growth of these groups, indicates that demand factors are consign-

five broad kinds of tasks carried out by the U.S. labor force:

Expert thinking. Solving problems for which there are no rules-based solutions. Examples include diagnosing the illness of a patient whose symptoms seem strange, creating a good-tasting dish from ingredients that are fresh in the market that morning, and repairing an auto that does not run well but that the computer diagnostics indicate has no problem. While computers cannot substitute for humans in these tasks, they can complement humans in performing them by making information more readily available.

Complex communication. Interacting with humans to acquire information, to explain it, or to persuade others of its implications. Examples include a manager motivating workers, a biology teacher explaining how cells divide, and an engineer describing why a new design for a DVD player is an advance over previous designs.

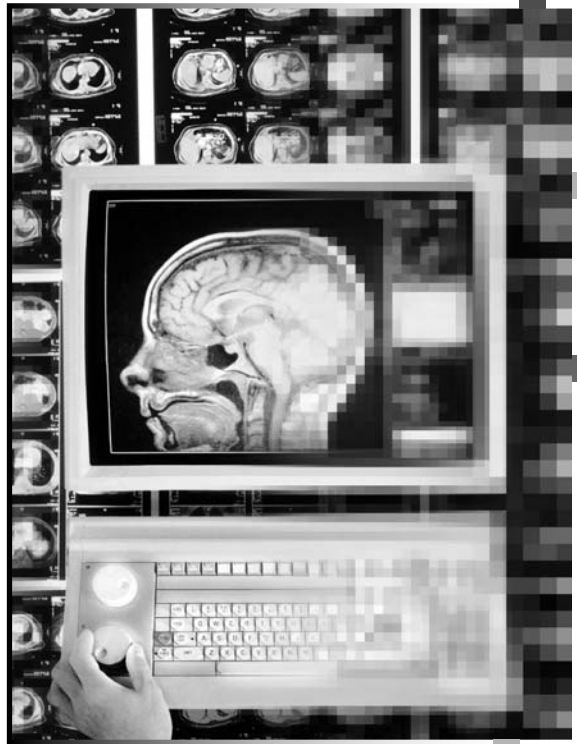
Routine cognitive tasks. Mental tasks that are well described by logical rules. Examples include maintaining expense reports, filing new information provided by insurance customers, and evaluating applications for mortgages. Because these tasks can be accomplished by following a set of rules, they are prime candidates for computerization.

Routine manual tasks. Physical tasks that can be well described using rules. Examples include installing windshields on new automobiles, and packaging pills for pharmaceutical firms. Since these tasks can be defined in terms of a set of movements to be carried out over and over in exactly the same way, they are also candidates for computerization.

Non-routine manual tasks. Physical tasks that cannot be well described as following a set of if-then-do rules because they require optical recognition and fine muscle control have proven extremely difficult for comput-

ers. Examples include driving a truck, cleaning a building, and setting gems in engagement rings. Computers do not complement human effort in carrying out most such tasks. As a result, computerization should have little effect on the percentage of the work force engaged in these tasks.

Earlier, we saw how the nation's occupational distribution has changed in the last



three decades. In the same way, we can look for changes in the nature of the tasks that comprise this work. While the Census does not ask about the content of work, a second survey does – the U.S. Department of Labor's Dictionary of Occupational Titles (DOT).

The DOT is a compilation of 12,000 detailed occupational descriptions, each containing professional observers' ratings of the training time required for the occupation, the occupation's physical and cognitive requirements,

and other characteristics. Because an occupation's details can vary across work sites, each occupation is rated by workers in multiple sites and the DOT provides an average of the ratings.

The DOT data is far from perfect. Updates are infrequent, making it difficult to track changes in tasks that occur within occu-

pattern recognition grew in frequency while rules-based tasks declined. Complex communication is important in management and in teaching and sales, among other occupations. As the work structure evolved toward these particular occupations, the frequency of tasks requiring complex communication grew steadily. The frequency of tasks requiring expert thinking – tasks that involved solving new problems – followed a similar growth path.

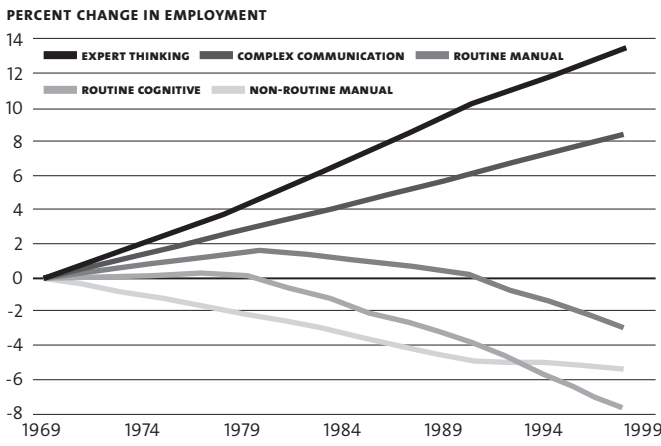
For rules-based tasks where computers can substitute for humans, the picture is one of decline. The share of the labor force employed in occupations that emphasized routine cognitive tasks remained quite steady during the 1970s and then declined quite precipitously over the next two decades.

The pattern for routine manual tasks that might be subsumed by automation is roughly similar: a slight rise during the 1970s and a steady decline thereafter. The share of the labor force working

in occupations that emphasize non-routine manual tasks declined throughout the period. In part, this reflects the movement of manufacturing jobs offshore.

The data in the chart on page 69 (occupations) and this page (tasks) are consistent with our description of computers' economic impacts. But correlation does not prove causation – the trend in both charts could have been caused by other factors. To make a stronger case, we must increase the level of detail to look at changes within industries. If the adoption of computers shifts work away from routine tasks and toward tasks requiring expert thinking and complex communication it should be easier to identify within

ECONOMY-WIDE MEASURES OF ROUTINE AND NONROUTINE TASK INPUT: 1969 - 1998

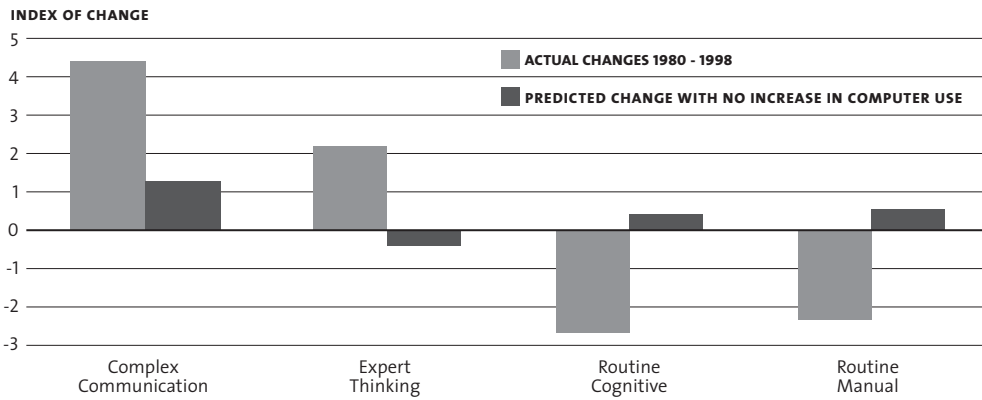


SOURCE: Revised version of figure from David Autor, Frank Levy and Richard J. Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics* 118 (November 2003): 4.

pations. Nonetheless, the DOT allows an approximate translation of changes in the distribution of occupations into changes in the kinds of tasks that people perform in the workplace. The chart above displays the trend for each of these five types of tasks. Each trend reflects changes in the numbers of people employed in occupations emphasizing that task. To facilitate comparisons, the importance of each task in the U.S. economy is set to zero in 1969, our baseline year. The value in each subsequent year represents the percentage change in the importance of each type of task in the economy.

A quick look at the chart shows that, consistent with our expectations, tasks requiring

WITHIN-INDUSTRY CHANGES IN TASK FREQUENCY FROM 1980 - 1998, AND PREDICTED CHANGES IN TASK FREQUENCY HAD THERE BEEN NO INCREASE IN COMPUTER USE.



SOURCE: Revised version of figure from David Autor, Frank Levy, and Richard J. Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics* 118 (November 2003): 4.

industries. Specifically, we can ask: are those industries that invested most heavily in computers the industries where we see the greatest changes in task structure?

The answer is yes. In the chart above, the left of each pair of bars describes the average change in task frequency within industries between 1980 and 1998. The height of the right bar in each pair is an estimate of the change in task frequency that would have occurred had there been no increase in computer use. A comparison of the bars in each pair shows that changes in task frequency have been concentrated in the industries experiencing the most rapid increases in computer use.

This pattern is particularly striking for routine cognitive tasks. The percentage of the labor force employed in jobs that consisted primarily of carrying out routine cognitive tasks declined substantially over these years. The chart shows that, in the absence of changes in computer use, the estimated percentage of the labor force working at routine cognitive tasks would have increased. The amount of routine information-processing

taking place in the economy grew substantially over these years, but increasingly this work was carried out by computers instead of people.

The case for the link between computerization and task change is strengthened by looking at the changes in tasks performed by high school graduates. Since 1970, industries that invested heavily in computers shifted their workforces away from high school graduates and toward college graduates. This comes as no surprise. On average, college graduates are better suited than high school graduates for jobs like product design, technical troubleshooting and managing – all tasks requiring expert thinking and complex communication. But if high school graduates in computer-intensive industries also saw their jobs shift toward these two kinds of tasks, it would be additional evidence of how deep computerization has reached into the workplace.

In fact, this has been the case. In the work with David Autor, we show that the past two decades have seen increases in the percentage of high school graduates working at jobs that emphasize complex communication and



substantial declines in the percentages of high school graduates working at jobs that emphasized routine cognitive or routine manual tasks. Consistent with our theory, these changes were concentrated in industries that experienced the greatest growth in computer usage.

WHY TASK CHANGES ARE ACTUALLY LARGER

While the chart on page 74 displays large changes in the tasks carried out by workers, the chart actually understates the changes that have taken place. Because the task content data from the Dictionary of Occupational Titles are updated infrequently, this chart displays only task changes resulting from shifts in the economy's mix of jobs. It does not reflect task changes that occur within jobs. But hundreds of examples show that task changes within jobs have been quite large.

Consider “exceptions processing” at Cabot Bank, a large New England retail bank. Ten years ago, each exceptions-processing clerk in the bank's back offices worked with paper checks and handled a single kind of exception – say, overdrafts. Within the customer's

account, the overdraft might be part of a more complicated set of transactions, but this was not the clerk's concern. The unit's manager described the work as “checking your brains at the door.”

Today, exceptions clerks handle all exceptions in an account – overdrafts, stop payments, address changes and so on – as they reconstruct what a customer was actually trying to do. If they want to advance, they are also expected to make suggestions to improve department operations. The job now requires both greater skills and more initiative.

The job of stockbroker has changed in similar ways. Twenty years ago, most stockbrokers provided buy and sell recommendations, company research and general conversation. Advising customers on other financial issues – the best way to save for a child's education – was beyond their job. Stockbrokers were paid a substantial commission on each customer trade. The commission was a “bundled” price that covered the cost of the trade as well as the cost of the research and conversation time.

By the late 1990s, Web-based trading through firms like E-Trade threatened to undermine this arrangement. A customer

could talk to a broker, but then avoid paying a hefty bundled commission by trading online. Customers could download online research as well.

Brokers have increasingly adopted a two-part response. They have changed their pricing so that they are paid a percentage of customer assets under management rather than a per-trade commission. And consistent with our argument here, they have expanded what they do to include financial advice (retirement planning, college savings planning and similar services not easily provided over the Web) that requires more knowledge and insight.

TASKS AND SKILLS

Computerization has altered the tasks American workers perform. Declining portions of the labor force are engaged in jobs that consist primarily of routine cognitive work and routine manual work – the types of tasks that are easiest to program computers to do. Growing proportions of the nation's labor force are engaged in jobs that emphasize expert thinking or complex communication – tasks that computers cannot do.

If the set of products and services produced in the economy did not change, there would be less and less good work for humans to do as advances in computerization increased the possibilities for substitution. Such a trend, however, would run directly counter to the profit motive. A task, once computerized, is potentially easy to replicate and so invites intense competition. The response to the competition is a constant drive to use advances in computer technology to develop new products and services – cell phones, DVDs, broadband Internet, computer-assisted surgery, financial derivatives, sensors in cars – the list is endless. This drive to develop, produce and market new products relies on the human

ability to manage and solve analytical problems and communicate new information, and so it keeps expert thinking and complex communication in strong demand.

THE NEXT 10 YEARS

In 1960, Herbert Simon took the risk of predicting how computers would change the mix of occupations by 1985. We take a similar chance, speculating on how computers will change the job market in the years ahead.

We will not look as far into the future as Simon did – 10 years will be sufficient for our purpose. But we will expand on Simon by considering a broader set of consequences. Simon focused on how computers would change the corporation's mix of occupations. From society's perspective, that change is the first step in a longer process. Out in the job market, the mix of occupations can change faster than workers can change their skills – a differential that computers have enlarged. Big wage changes are the result, as demand for some workers increases while demand for others plummets. Big wage changes, in turn, spur individual responses – seeking new training, going on to the disability roles. Big wage changes can also motivate political responses – changes in the tax laws, programs to improve education, limits on imports. We cannot pretend to predict this entire chain of events, but we will sketch some possibilities.

Mary Simmons's Job

A starting point is the job of Mary Simmons, a telecommunications customer service representative. When Mary started in 1975, her work primarily consisted of explaining the company's policies, services and products to customers in nearby towns. She kept most of the information she used in her head. Today, Mary still explains her company's policies and products to customers, but relies on a

computerized database for access to the information she needs. The database's large capacity complements Mary's communication and problem-solving skills, enabling her to do work that formerly required several people – addressing hundreds of questions each day from customers in several states about a large variety of products and service plans.

Computers have also changed Mary's job in another way. Her employer now uses technology to monitor most aspects of Mary's

and translate it into a question that her computerized database can answer. Then she needs to converse interactively (and tactfully) to be sure the customer understands her answer as well as any sales message she delivers.

A little of this interaction is within a computer's reach. Her employer is experimenting with a computerized conversational interface that may be able to provide answers to routine questions. But Mary's job requires conversation over such a broad range of topics that her

Our Simonesque prediction is that the major consequence of computerization will not be mass unemployment, but a continued decline in the demand for moderately skilled and less-skilled labor.

work: how many calls she answers per hour, the length of each call, the content of selected calls, and the number of minutes Mary takes for bathroom breaks or to catch up on paperwork. While technology creates the possibility of monitoring, its use reflects Mary's bargaining position. Few employees willingly accept such monitoring. But Mary and her fellow operators are not in a sufficiently strong position to prevent monitoring while earning their present salaries.

With or without monitoring, it is unlikely that Mary Simmons's job will exist many years longer. To be sure, possibilities for total computer substitution are modest. Many of the answers Mary gives are ultimately rules-based responses, but Mary's interaction with customers is, in computer terms, very complex. When a customer calls, Mary must first extract the words from her caller's conversational speech, dealing with "umms," sentence fragments, ellipses, accents and other irregularities. She must clarify the caller's problem

job will require the flexibility of human information-processing for the foreseeable future. It is likely, however, that the human will not be sitting in the United States.

Other countries – notably India – are making big strides in developing call-center jobs like Mary's. Operators are given typical American names and are trained to speak with regional American accents. Modern telecommunications technology gives the conversation the clarity of a local call. Drop-down menus on an operator's terminal contain glossaries of everyday speech so that an operator selling professional basketball tickets will not have to ask the caller to explain what he means by "Shaquille." Since an operator in Bangalore makes less than a quarter of Mary's salary, it is easy to imagine Mary's job moving overseas before very long.

Where Jobs Will Be Lost and Gained

Computer substitution had its greatest initial impact on blue-collar and clerical jobs

– rules-based jobs. The story of Mary Simons’s job illustrates our prediction that this impact will expand upward in the wage distribution into jobs that involve some pattern recognition but still have a large rules-based component. Think about income tax preparation. The tax system is based on rules – rules that are built into software like *TaxCut* and *TurboTax*. While preparation of complex tax returns requires expert human judgment, many other tax returns do not, and so it is not surprising that the preparation of routine income tax returns is beginning to move offshore.

In some instances, this expanded substitution will reach into high-wage jobs. A highly publicized case has been the shift of programming jobs to India and China.

We can think of this shift as stemming from the combination of three factors. One, at least for the moment, is the low wages of Indian and Chinese programmers. A second is the way that software code written abroad can be transported instantaneously to U.S. customers. The third factor is the nature of the knowledge required for programming. Creating an advertising campaign for Fritos requires extensive tacit knowledge of the U.S. market. By contrast, debugging software modules for an Oracle database requires knowing a self-contained set of programming rules that is available to students everywhere.

While the movement of programming jobs offshore illustrates that even some quite skilled jobs are susceptible to outsourcing, we see these as exceptions. The greatest impacts of computer substitution (including outsourcing) will be on jobs like call-center customer service reps and blue-collar manufacturing jobs – jobs in the lower middle of

the wage distribution now paying \$20,000 to \$35,000 a year.

Thus, our Simonesque prediction is that the major consequence of computerization will not be mass unemployment, but a continued decline in the demand for moderately skilled and less-skilled labor. Job opportunities will grow, but job growth will be greatest



in higher skilled occupations in which computers complement expert thinking and complex communication to produce new products and services. At the same time, more moderate expansion will occur in low-end, low-wage service-sector jobs.

This declining demand for less-skilled labor was implicit in Simon’s 1960 predictions, and was given a modern face by Brookings Institution economist Gary Burtless some years later. In 1990, Burtless assessed the fear that the U.S. job market would become dominated by low-skilled, low-wage work. His conclusion turned that fear on its head: “Ironically, [less-skilled workers’] labor market position could be improved if the U.S. economy produced *more*, not fewer, jobs requiring limited skill.”

What seemed like ivory-tower logic was

actually basic economics. The wage that a job pays is largely determined by supply and demand. In the early 1970s, a 35-year-old man with a high school diploma averaged \$35,000 per year (in 2001 dollars). In the late 1980s, when Burtless was writing, a 30-year-old man with a high school diploma averaged \$30,000 per year (incidentally, the same \$30,000 figure holds today.) In the interim, the number of traditional jobs for male high school gradu-



ates had grown slowly – more slowly than the number of men who wanted them. Wages of less-educated workers declined as men (and women) competed for the jobs that were left. The same declining demand helps to explain why Mary Simmons and her fellow operators were not in a position to reject the computer monitoring of their work.

THE DETAILS OF ECONOMIC PROGRESS

Given these problems, we might ask why U.S. presidents routinely embrace new technology and expanded trade (of which outsourcing is a part). The long-run answer is clear: technology and trade are both engines of economic growth that ultimately raise the national standard of living. But getting to the long run can

be messy since economic growth in the short run usually creates losers as well as winners.

During the Industrial Revolution, the short-run impact of growth was almost the opposite of what we see today. Technology favored not high-skilled workers but low-skilled workers, as machines combined with unskilled labor to make products ranging from textiles to bicycles to guns. It was higher skilled workers – weavers, clockmakers and other craftspeople – whom the technology displaced.

In some later periods, technology distributed its benefits more evenly. When John Kennedy was president, he could say “a rising tide lifts all the boats” and be substantially correct. Kennedy governed in a lucky economic time when technology and trade did not strongly favor one skill group over another, and when economic growth raised incomes for most workers – even in the short run.

Politicians still invoke Kennedy’s language, but it no longer applies; the forces driving economic growth now increase demand for highly skilled workers while they reduce demand for less-skilled workers. In Ronald Reagan’s eight years in office, the nation’s GDP grew by 23 percent while the earnings of the average 35-year-old male high school graduate fell by almost one-sixth and the college/high-school earnings differential grew from 20 to 45 percent.

During Bill Clinton’s first term, the earnings of high school graduates fell still more. While these earnings recovered modestly in the boom of Clinton’s second term, the college/high-school differential continued to grow. This growth continued during the recent recession as the earnings of college graduates rose slightly and the earnings of high school graduates held steady. We pre-

dict that this technological bias against less-skilled workers will continue for at least the next decade.

Sustained shifts in the demand for labor lack the drama of mass unemployment. But, if ignored, these shifts can lead to extraordinary pain for many workers and can ultimately threaten the stability of society. In the current situation, one bad outcome would be a hardening of the lines dividing economic classes. The process is easy to imagine. As income gaps expand, human nature dictates that higher income groups see that they have less in common with the rest of the population. In a political process responsive to money, the lack of perceived common interests translates into less redistribution and less protection for workers who are losing ground. As technology tilts the playing field against less-educated workers, these policy changes would tilt it further, reducing individual opportunity and upward mobility.

In a different, but equally bad outcome, job loss and insecurity would fuel a political movement to turn back the economic clock – for example, restricting international trade. To the extent that these policies succeed, the result would be a frozen economic landscape that offers some short-run employment protection at the cost of long-run stagnation and decline.

HOW WINNERS TREAT LOSERS

As these possibilities illustrate, advances in computerization and computer-assisted trade have placed us in a potentially precarious position – one in which a significant fraction of workers is likely to experience economic hardship. There are no magic bullets here, but economic theory does provide a useful way of thinking about these problems.

The argument is part of what is called Kaldor-Hicks improvements and begins by

granting that economic growth can create losers as well as winners. Under these conditions, the argument goes, growth still represents a societal improvement – a gain in economic efficiency – if the winners could compensate the losers and still be better off themselves. The argument does not require that compensation actually be paid. But that is the important social implication, with compensation for the losers coming through government benefits or private charity. Note that

If enough people come to see the job market as stacked against them, the nation's institutions will be at great risk.

compensation will not come through the market, since the market is creating the winners and losers in the first place.

Why should those better off pay compensation through taxes or charity? Enlightened self-interest. Our market economy exists in a framework of institutions that requires the political consent of the governed. People doing well today have a strong interest in preserving this consent. If enough people come to see the job market as stacked against them, the nation's institutions will be at great risk.

Examples of compensation include subsidized health insurance coverage for low-income families and retraining opportunities coupled with temporary income support. Equally important are policies to improve life chances for the next generation, especially intensive efforts to improve education, so that the children of today's workers will be in a stronger position to earn a decent living.

In economic terms, improved education

is required to restore the labor market to balance. Recall Gary Burtless's point: the falling wages of lower skilled jobs reflect the fact that demand was not keeping up with supply. If our predictions are right, this trend will continue as blue-collar and clerical jobs continue to disappear.

Better education is an imperfect tool for solving the problem. The job market is changing fast, and improving education is a slow and difficult process; even the best education cannot reach everyone. But it remains the best tool we have to prepare the population for a rapidly changing job market.

Beyond economics, better education is also needed to prepare for what will be a challenging political time. In less than a decade, computers have created many workplace tensions: wage inequality, the monitoring of work, lack of employee privacy, and a never-ending workday in which cellphones place employees constantly on call. Such tension is not new. What is new is the increasing power of information technology to intrude on the lives of every citizen, along with the growing complexity of the resulting social issues.

In the past, Americans have used the political process to address such issues through laws that guarantee the right to bargain collectively, that mandate overtime pay and that regulate the use of surveillance technologies. Many of these new problems are candidates for legislation as well, since they require collective solutions. For example, a firm may be reluctant to drop intensive employee monitoring unless it can be sure that competing firms are dropping it as well.

Historically we have relied on our educational system both to prepare people to earn a living and to teach them the values, knowledge and skills to participate in a democratic society. Because both goals are increasingly important, it is reasonable to ask whether we

are asking schools to do too much – whether one agenda must now crowd out the other.

We believe the answer is no. The skills needed to excel at expert thinking and complex communication – the job skills that will grow in importance – are not specific subjects that compete for instructional time with, say, social studies or science. Rather, they are strategies for tackling problems that cannot be solved by applying sets of rules. And they are also strategies for helping others to make sense of the many kinds of information to which we are all exposed.

Indeed, students need to learn expert thinking and complex communication in order to study science or history. In the field of genetics, for example, students need to understand that the same advances in biology that make it possible to treat previously incurable genetic diseases will also make possible “customized offspring,” which in turn raise complex ethical and social issues. The skills critical to expert thinking and complex communication are just as important to meeting these goals as they are to earning a living in a work world filled with computers.

Not so long ago, the economy exhibited a comforting regularity. Unemployment changed in recessions and expansions, but the same jobs that were lost on downturns were largely replaced on the upturns. Because the job market was fairly stable, the policies that interacted with the job market – the tax system, education, training – could be stable as well.

That world is now largely gone. Many of the jobs lost in the post-2000 recession – clerical and factory jobs lost to automation, call-center jobs lost to India, manufacturing jobs lost to China – will not be coming back. This dynamic environment requires new policies, and the first step in creating those policies is to recognize the new realities. **M**