Dancing with Robots: Human Skills for Computerized Work

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How do we ensure American middle class prosperity in an era of ever-intensifying globalization and technological upheaval? That is the question we are trying to answer with NEXT—a project at Third Way that taps into cutting edge research by top American academics.

What's NEXT?

Well before the Great Recession, middle class Americans questioned the ability of the public sector to adapt to the wrenching forces re-shaping society. And as we've begun to see a "new economic normal," many Americans are left

wondering if anyone or any institution can help them, making it imperative that both parties—but especially the self-identified party of government—re-think their 20th century orthodoxies.

With this report Third Way is continuing NEXT—a series of in-depth commissioned research papers that look at the economic trends that will shape policy over the coming decades. In particular, we're bringing this deeper, more provocative academic work to bear on what we see as the central domestic policy challenge of the 21st century: how to ensure American middle class prosperity and individual success in an era of ever-intensifying globalization and technological upheaval. It's the defining question of our time, and one that as a country we've yet to answer.

Each of the papers we commission over the next several years will take a deeper dive into one aspect of middle class prosperity—such as education, retirement, achievement, and the safety net. Our aim is to challenge, and ultimately change, some of the prevailing assumptions that routinely define, and often constrain, Democratic and progressive economic and social policy debates. And by doing that, we'll be able to help push the conversation towards a new, more modern understanding of America's middle class challenges—and spur fresh ideas for a new era.

In *Dancing with Robots*, Frank Levy and Richard Murnane make a compelling case that the hollowing out of middle class jobs in America has as much to do with the technology revolution and computerization of tasks as with global pressures like China. In so doing, they predict what the future of work will be in America and what it will take for the middle class to succeed. The collapse of the once substantial middle class job picture has begun a robust debate among those who argue that it has its roots in policy versus those who argue that it has its roots in structural changes in the economy.

Levy and Murnane delve deeply into structural economic changes brought about by technology. These two pioneers in the field (Murnane at Harvard's Graduate School of Education

and Levy at MIT) argue that "the human labor market will center on three kinds of work: solving unstructured problems, working with new information, and carrying out non-routine manual tasks." The bulk of the rest of the work will be done by computers with some work reserved for low wage workers abroad. They argue that the future success of the middle class rests on the nation's ability "to sharply increase the fraction of American children with the foundational skills needed to develop job-relevant knowledge and to learn efficiently over a lifetime." As for the state of our schools, Levy and Murnane point out something quite profound, "American schools are not worse than they were in a previous generation. Indeed, the evidence is to the contrary. ... Today's education problem stems from the increased complexity of foundational skills needed in today's economy."

The paper evocatively describes the exact kind of work tasks that are now, or will be, automated. With the constant upgrades in computer speed and capacity, Levy and Murnane point out that computers will ultimately perform nearly all "tasks for which logical rules or a statistical model lay out a path to a solution," including "complicated tasks that have been simplified by imposing structure."

They posit that the future of middle class work will necessarily have to rely on uniquely human brain strengths: "flexibility—the ability to process and integrate many kinds of information to perform a complex task, [such as] solving problems for which standard operating procedures do not currently exist, and working with new information— acquiring it, making sense of it, communicating it to others."

For sure, over the past decade we have lost millions of manufacturing jobs to China. But we have probably reached the end of that story as Chinese wages continue to rise. Yet we have lost the airline ticket salesperson to a kiosk; the check-out clerk to the scanner, and the factory floor worker to the machine. Each year, computers simply get better, faster, and more powerful. Meanwhile, both parties profess an

undying commitment to the middle class. But is either party proposing anything remotely close to preparing the current and next generation for solid work in the midst of technological change?

The policy challenge that flows from this paper goes well beyond calls for more years of education or better access to education. In order to prepare young people to do the jobs computers cannot do we must re-focus our education system around one objective: giving students the foundational skills in problem-solving and communication that computers don't have. As the authors illustrate, these skills are not just the skills of professionals with advanced degrees. What computers have done is to make even traditional blue collar jobs like auto-mechanic—dependent upon one's ability to problem solve and to communicate. These insights are critical to thinking creatively about the challenge of job creation in the 21st century.

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On March 22, 1964, President Lyndon Johnson received a short, alarming memorandum from the Ad Hoc Committee on the Triple Revolution. The memo warned the president of threats to the nation beginning with the likelihood that computers would soon create mass unemployment:

> *A new era of production has begun. Its principles of organization are as different from those of the industrial era as those of the industrial era were different from the agricultural. The cybernation revolution has been brought about by the combination of the computer and the automated self-regulating machine. This results in a system of almost unlimited*

productive capacity which requires progressively less human labor. Cybernation is already reorganizing the economic and social system to meet its own needs. [2] "

The memo was signed by luminaries including Nobel Prize winning chemist Linus Pauling, *Scientific American* publisher Gerard Piel, and economist Gunnar Myrdal (a future Nobel Prize winner). Nonetheless, its warning was only half right. There was no mass unemployment—since 1964 the economy has added 74 million jobs. But computers have changed the jobs that are available, the skills those jobs require, and the wages the jobs pay.

For the foreseeable future, the challenge of "cybernation" is not mass unemployment but the need to educate many more young people for the jobs computers cannot do. Meeting the challenge begins by recognizing what the Ad Hoc Committee missed—that computers have specific limitations compared to the human mind. Computers are fast, accurate, and fairly rigid. Human brains are slower, subject to mistakes, and very flexible. By recognizing computers' limitations and abilities, we can make sense of the changing mix of jobs in the economy. We can also understand why human work will increasingly shift toward two kinds of tasks: solving problems for which standard operating procedures do not currently exist, and working with new information— acquiring it, making sense of it, communicating it to others.

How Computers Do What They Do

The job of washing dishes consists of six tasks: clearing the dishes from the table, applying soap and hot water, scrubbing, rinsing, drying, and stacking dishes in the cabinet. The technology we call a "dishwasher" substitutes for human effort in four of these tasks, but not in the other two. Technology usually changes work by changing how specific tasks are performed.

To begin to see computers' abilities and limitations, consider four tasks:

- In most U.S. airports, the task of dispensing airline boarding passes is largely performed by self-service kiosks rather than by desk agents. Agents continue to handle rebooking, helping to locate lost baggage, and other pieces of the original job.

- In a Ford plant in Louisville, Kentucky, industrial robots perform the task of applying adhesive that will fasten the windshield of a Ford Escape. Other robots equipped with suction cups then place the windshield into the Escape's frame. Applying adhesive and inserting windshields used to be performed by autoworkers. [3]

- You test Siri—the iPhone digital assistant—to see if it can perform the task of answering a common sense question: "Can a dog jump over a house?" Siri gives you a set of directory listings of kennels and says: "Ok. One of these kennels looks fairly close to you." [4]

- A vascular surgeon watches continuous X-ray images on a digital screen as she inserts a coil into an arterial aneurism next to the brain of a young man. Without continuous imaging, the surgeon would have relied on one X-ray of the brain taken before the operation began, a far riskier procedure.

In the first and second example, computers *substitute* for human work—the outcome feared by the Ad Hoc Committee. The third example is odd: Siri's software understands the spoken words and recognizes they form a question, but a four-year-old child could give a better answer. In the fourth example, computers *complement* human skills in carrying out a task more effectively than the skilled human could do without the new technology.

To understand this pattern of outcomes, start with two facts:

- All human work involves the cognitive processing of information. The financial analyst who reads numbers in a spreadsheet, the farmer who looks to the sky for signs of rain, the chef who tastes a sauce, the carpenter who feels his hammer as it hits a nail—all these men and women are processing information to decide what to do next or to update their picture of the world.

- Computers execute rules. Some of the rules involve arithmetic (6 x 9 = 54). Other rules involve logical conditions (If [Rainfall in Last 24 Hours > .5 inches] Shut Off Sprinkler System). We can think of a properly running computer program as a series of rules that specify an action for each contingency.

These facts indicate that a computer can substitute for a human in performing a particular task when two conditions are satisfied:

- *An Information Condition:* All information necessary to carry out the task can be identified and acquired in a form that computers can process.

- *A Processing Condition:* The information processing itself can be expressed in rules.

The *Information Condition* is obvious, but we will see shortly that it can be hard to fulfill. The rules to which the *Processing Condition* refers can be either deductive or inductive.

Deductive rules express information processing as a logical, step-by-step procedure. In the self-service airport kiosk, information from a credit card and information from the airline's reservation data base are processed into the information on a boarding pass. This kind of processing can be expressed in a series of deductive rules—for example,

> *Does the name on the credit card match a name in the reservation data base?*
>
> *If Yes, check for a seat assignment.*

> *If No, instruct customer to see desk agent.* "

Information processing expressed in deductive rules is often called rules-based logic.

Inductive rules are used to describe information processing that can't be articulated as a series of logical steps. These rules take the form of statistical equations that model the relationship between the information inputs and the processed output. The equations are estimated, or "trained," using samples of historical cases. The estimated equations are then used to process new cases. Information processing expressed in inductive rules is often described as pattern recognition—using statistical modeling to look for patterns in data.

Fannie Mae's *Desktop Underwriter*, software widely used by mortgage brokers to assess a mortgage applicant's risk, is based on inductive rules. [5] The software processes information from the mortgage application—the applicant's credit history, the property type, the property's loan-to-value ratio, the applicant's liquid reserves—into a probability that the mortgage will default within, say, four years. Low credit ratings and low liquid reserves are both related to a higher likelihood of default, but these relationships can't be expressed as a series of logical steps. To capture the relationship, Fannie Mae statisticians use historical samples of approved mortgages to estimate ("train") the weights to be attached to variables like a person's credit rating and the loan-to-value ratio in an equation predicting the default probability. That estimated equation (an inductive rule) forms the heart of the *Desktop Underwriter* that brokers now use to predict the probability of default in new mortgage applications. A mortgage broker will then use her experience, intuition and, perhaps, other information to judge whether the estimated probability constitutes an acceptable risk.

The ability to articulate rules—deductive or inductive— explains the first two examples above. The task of issuing a

boarding pass can be fully expressed in deductive rules because most answers to the software's questions can be predicted and any unanticipated answer can trigger the message, "Unable to Continue: Please See a Desk Agent."

On the Ford Escape assembly line, the moving robot arm is guided by perception software, based on inductive rules, that continuously updates the time and distance between windshield and automobile frame to correct the arm's movements.

Siri uses two sets of inductive rules: one to recognize spoken words and a second to process the words into meaning and to form the question. The first set of rules worked correctly. The second set didn't.

In the fourth example, continuous X-rays improved the surgeon's performance in inserting the coil but all the surgeon's skills were still required.

We turn next to the questions of why Siri failed and what makes the surgeon's example different.

What Computers Don't Do (Yet)

The human mind's strength is its flexibility—the ability to process and integrate many kinds of information to perform a complex task. The computer's strengths are speed and accuracy, not flexibility, and computers are best at performing tasks for which logical rules or a statistical model lay out a path to a solution. Much of computerized work involves complicated tasks that have been simplified by imposing structure. [6]

In theory, a person could order John Grishman's latest novel, *The Racketeer*, from Amazon.com by writing Amazon an unstructured, chatty email. In reality, a computer does not do a good job of extracting the relevant information from thousands of chatty emails, particularly since people often forget a book's exact title or, as above, misspell the author's name— problems that require the computer to check with the customers on what they meant to say. For that reason,

Amazon simplifies the information processing problem by imposing structure. You order a book by clicking a button next to the book that says "Add to Cart." You specify the book as a gift by checking a box. You start to write your address by entering your last name into a box marked "last name."

The airport pass kiosk that requires your credit card imposes structure on the task of preparing a boarding pass. Engineers have simplified the robot arm's task by imposing a physical structure in which the automobile frame and the windshield pallet occupy precise locations.

As chip speeds have increased and large data sources—"big data"—have become available, structure is slowly being relaxed. In 1962, IBM's *Shoebox* created a sensation by its ability to recognize 16 words at the Seattle World's Fair. [7] Today, iPhone's Siri responds accurately to a sports fan's unstructured request for a New York Knicks' score. But even with computers' greater speed, there are many tasks computers cannot perform because either the Information Condition or the Processing Condition is not satisfied.

Begin with the Information Condition. You're driving your car and see a softball rolling into the street ten feet in front of you. A laser beam from a computerized collision avoidance system detects a ball 3 ½ inches in diameter—nothing too dangerous. A newly licensed teenage driver might react the same way. But you know from experience that a ball rolling into the street is often followed by a young child chasing the ball so you step on the brakes. [8] This piece of information stored in memory—children often follow balls into the street—is central to correctly performing the task.

The connection between the ball and the child is an example of common sense—the thousands of facts and relationships we know, each too obvious to notice, that are necessary to perform many real world tasks ("When you drop a hammer, it falls down, not sideways"). Computers only process the information they are given or can infer and so they often lack the common sense needed for the right response. Siri can

give you a New York Knicks' score because its inductive rules have been trained to recognize sports score questions. Siri failed on the jumping dog question because engineers don't yet know how to put enough common sense into software.

Driving through a city requires much more common sense than recognizing the implications of a softball rolling in front of a moving car. It also requires strong navigational skills to stay on the road. For these reason, Google's autonomous car has simplified its job by not relying solely on sensing the environment, as a human driver would do. Rather, it carries a navigation backbone of hand-edited digitized maps of the limited number of roads on which it is being tested and a human driver to deal with emergencies. [9]

The Processing Condition can be equally problematic for complex cognitive problems, but also for "simple" physical tasks. While attending a reception, you navigate through a crowded room, quickly and safely, to select an apple from a bowl of fruit. A three- year-old child can perform this task and yet the required information processing is very hard to express in software. In contrast to the robot arm on the assembly line that moves between fixed positions, the child's problem is much less structured. Her task begins with a two-dimensional pattern of photons projected onto her retina—the visual information from the room. Her brain processes this pattern to make sense of the room—the locations of human legs, furniture legs, the side of a couch, and the bowl of fruit itself. She then has to process this understanding into decisions on how to move. The earlier example of the vascular surgeon involves similar problems: processing digital information from a continuous X-ray to make sense of the patient's vascular system and processing this understanding into hand movements as she guides the coil toward the aneurism—physical movements that are extremely hard to program.

An example of cognitive complexity arises in solving new problems—problems the "rules writers" didn't anticipate. In these situations, the human mind's flexibility becomes very

important. Tasks involving innovation and design fit this description, but tasks in many other jobs raise new problems as well.

Arthur Edwards (not his real name), a twenty-seven year-old auto technician, lives in Michigan and works in a Honda dealership. Edwards solves many problems using rules-based diagnosis—step-by-step procedures that apply computerized diagnostic tools. For example, testing electronic circuits involves a standard sequence of electrical current readings using a digital multimeter. But there are limits to the process.

> *The test results depend on the circuit. But the test results also depend on establishing a proper ground connection with one of the probes of the multimeter. If the probe is touching a corroded area, the connection will be poor or non-existent and the multimeter will make it look like a circuit problem. An experienced technician will know when re-testing is necessary because the initial results weren't what they expected. An inexperienced technician may assume the test results are accurate, which will send him down an entirely wrong branch of the diagnostic tree.*

Writing rules to test entire systems—for example, a transmission—compounds the problem of anticipating everything that might go wrong. Edwards passed along the following example from another technician:

> *A customer brings in a car where the air conditioning works while the vehicle is in motion, but the air blew warm when the car was stopped at a light. The first thing to check is the compressor—the compressor operates normally. You have to check the refrigerant— the system is fully charged with refrigerant. The car's fans come on at the correct time. All other electrical*

signals look normal. In other words, the tests all indicate the system should be working properly but it isn't.

At that point, you just have to start checking everything that might be a cause. Which means you have to know everything that might be a cause—even things you would normally take for granted. It turned out that the vehicle has been in a front end collision. When the front end had been repaired, they had reversed the power and ground wires to the radiator fan. When the car stopped for a light, the radiator fan ran backwards and so radiator heat was being blown onto the air conditioning condenser. Switching the wires back solved the problem.

In many cases, rules-based diagnostics can solve a problem particularly since technicians talk with each other and with the factory to update the rules. But when the rules don't work, then Edwards has to fall back on three skills. He has an extensive knowledge of automobiles. He can practice metacognition—the ability to recognize that one problem-solving strategy is not working and it is time to switch to another. He can communicate the problem to other technicians and to the factory technical assistance line to see if someone else has solved the problem. Computers can answer structured knowledge questions (think Watson competing on *Jeopardy*). But metacognition and unscripted communication are hard to computerize. Later we describe how humans acquire these skills.

Figure 1: Varieties of Computer Information Processing [10]

Increasingly Difficult to Program →

	Rules-Based Logic	Pattern Recognition	Human Work
Variety	Computer Processing using Deductive Rules	Computer Processing using Inductive Rules	Rules cannot be Articulated and/or Necessary Information cannot be Obtained
Examples	Calculate Basic Income Taxes Issuing a Boarding Pass	Speech Recognition Predicting a Mortgage Default	Writing a Convincing Legal Brief Moving Furniture into a Third Floor Apartment

The work computers can and can't do (today) is summarized in a spectrum running from tasks expressed in deductive rules to tasks that can't be computerized at all—i.e. Human Work (Figure 1). Human work includes the "high skilled" unstructured tasks of writing a convincing legal brief and repairing automobiles. But because many unstructured physical tasks are easy for humans and hard for computers, Human Work also contains the "low skilled" work of moving furniture into an apartment. While computers have difficulty substituting for humans in either kind of work, computers frequently complement humans in the high skilled work—a lawyer can conduct a computerized search of legal data bases and a mechanic can use computer-based diagnostic tools.

How Computers are Changing Available Jobs and Demands for Human Skills

Computers usually substitute for people in performing specific tasks—not whole jobs. But substituting for people in tasks still means fewer jobs than would otherwise be the case. Bank tellers are an example. ATMs now handle large numbers of deposits and withdrawals—tasks that used to take a significant fraction of a teller's time. As deposits and withdrawals have been computerized, fewer tellers are needed to serve a given number of customers. Between 1990 and 2011, total U.S. employment grew by 18% while the number of bank tellers grew by a slower 8%.

Reinforcing this substitution, when a task can be expressed in deductive rules (standard operating procedures), it is easier to

computerize, but also easier to explain to someone 5,000 miles away. [11] As a consequence, many tasks that are candidates for computer substitution are also candidates for offshoring. Assembly line work is performed by robots and also sent to China to be carried out by human workers. Call center work that is heavily scripted (rules) is programmed on language processing software and is also sent to India, where low-wage workers carry it out.

At the same time, advances in computerization have also created many new jobs. In 2012, 3.5 million persons worked directly in creating computer infrastructure—software developers, systems analysts, persons who optimize the placement of web-based ads. And many of the 2.4 million persons working as financial specialists were in jobs that would not have existed if computers had not made it possible to deliver services at affordable prices. [12]

As we sum up these impacts for the U.S., we know occupations grow or decline in importance for many reasons. The logic of Figure 1 suggests that changes in the U.S. occupational structure over the last 30 years should demonstrate one pattern in particular:

> *Between 1979 and 2009, adult employment grew by approximately 49%. Employment in occupations where computer substitution was possible should have grown more slowly than 49%. Occupations that grew faster than 49% should not have been candidates for computer substitution and may have been occupations that computers enable or complement like the job of auto mechanic.*

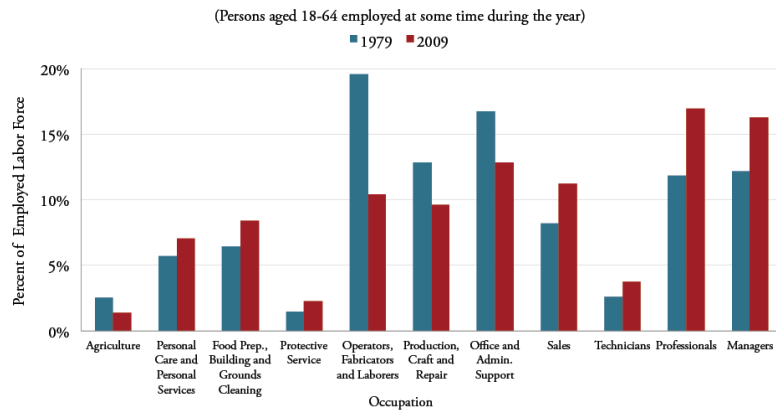**Figure 2: Occupational Distribution – 1979; 2009 [14]**

■ 1979 ■ 2009

Figure 2 compares the 1979 and 2009 U.S. occupational distributions for working men and women, aged 18-64. [13] Occupations in the figure are listed from left to right in order of increasing average pay. The figure indicates the occupational distribution has hollowed out—occupational shares at either end of the distribution have increased in importance while occupational shares in the middle of the distribution have declined. The hollowing out is the result of multiple factors, but it is consistent with the idea that occupations subject to computer substitution grow relatively slowly. Low wage work—Personal Care, Personal Services, Food Preparation, and Building and Grounds Cleaning—have all grown in importance and all involve non-routine physical work that is hard to computerize. Technicians and Professional and Managerial Occupations also have grown in importance. All involve abstract, unstructured cognitive work that is hard to computerize. Moreover, all rely on computers as complements including jobs like Network Manager that wouldn't exist without computers. By contrast, occupations in the middle of the distribution—Machine Operators, Production, Craft and Repair Occupations, Office and Administrative—have declined in importance. From the perspective of 1979, each of these occupations contained significant amounts of routine work that could be expressed in deductive or inductive rules and so were candidates for computer substitution and/or offshoring.

Occupational projections by the Bureau of Labor Statistics (BLS) for the year 2020 forecast a continuation of most of the

trends displayed in Figure 2. [15] The BLS projects total employment growth of 14.3% between 2010 and 2020, with the fastest growing occupations involving unstructured problem-solving, working with new information, and non-routine physical activity: Healthcare Support Occupations (+34.5%), Healthcare Practitioners and Technical Occupations (+25.9%), Community and Social Service Occupations (+24.2%), Construction and Extraction Occupations (22.2%), Computer and Mathematical Occupations (+22%). Conversely, occupations with potentially strong computer substitution are projected to grow by less than 14.3%: Production Occupations (+4.2%), Office and Administrative Support Occupations (10.3%). [16]

The actual nature of work—the tasks people perform—has changed faster than these occupational numbers suggest. Consider the work of a secretary. As defined in the U.S. Department of Labor's *Occupational Outlook Handbook* for 1976: "*Secretaries relieve their employers of routine duties so they can work on more important matters.*" [17] Included in "routine duties" were typing and filing and indeed, many high school-educated secretaries in 1976 spent their entire workday typing and filing. But with the development of word processing programs—*WordStar*, *WordPerfect*, and later Microsoft *Word*—a growing number of professionals found it more efficient to type their own letters and memos rather than dictate them to secretaries. Subsequent advances in computerized speech recognition accelerated this trend, further driving down the demand for typists. Electronic documents substantially reduced the time needed to maintain files. The job of secretary still exists but the job definition now puts a greater emphasis on solving unstructured problems and on interpersonal communication as described in the *Occupational Outlook Handbook* for 2000:

> "*Office automation and organizational restructuring have led secretaries to assume a wide range of new responsibilities once reserved for managerial and*

professional staff. Many secretaries now provide training and orientation to new staff, conduct research on the Internet, and learn to operate new office technologies. [18]

Working with MIT economist David Autor, we examined how changes in the occupational distribution of the U.S. labor force over the period 1960-2009 affected the types of tasks U.S. workers carried out. Our first step was to describe five broad types of workplace tasks: [19]

- **Solving Unstructured Problems:** Tackling problems that lack rules-based solutions. Examples include a doctor diagnosing an illness with strange symptoms, a mechanic repairing an automobile problem not described in the factory manual, a plumber fixing a complicated plumbing problem in an old house, a lawyer writing a convincing legal brief, a chef creating a new dish from ingredients that are fresh in the market that morning. Computers cannot replace the human work in these tasks, but computers frequently complement human work by making information more readily available—a plumber using the Internet to find a source for an obscure plumbing fixture.

- **Working with New Information:** Acquiring and making sense of new information for use in problem-solving or to influence the decisions of others. Examples include a manager motivating the people whose work she supervises, a biology teacher explaining how cells divide, a motel manager deciding whether a new air conditioner represents a useful upgrade, an engineer describing why a new design for a video streaming service is an advance over previous designs.

- **Routine Cognitive Tasks:** Performing mental tasks that are well described by deductive or inductive rules. Examples include maintaining expense reports, accepting bank deposits, calculating tax liabilities from information about earnings, expenditures, and family composition. Because these tasks can be accomplished by following a set of rules, they are prime candidates for computerization.

- **Routine Manual Tasks:** Carrying out physical tasks that can be described using deductive or inductive rules. Examples include assembling book orders in an Amazon warehouse, testing samples of newly fabricated computer chips, inserting windshields on automobile bodies, and counting and packaging pills into containers in pharmaceutical firms. These tasks can be performed with precise, repetitive movements that make them candidates for computerization.

- **Non-Routine Manual Tasks:** Carrying out physical tasks that cannot be well described in rules because they require optical recognition and fine muscle control that have proven difficult to program. Examples include safely 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 workforce engaged in these tasks.

The occupational distribution and the nature of work are changing, in part, because computers increasingly perform the two types of routine tasks while the three other types of tasks remain largely human work.

Given how easily computers exchange information, the inclusion of Working with New Information as a major type of task may seem surprising. Making sense of new information remains important because all information is ambiguous: there is no guarantee that the recipient of information interprets it as the information's author intended.

Twenty-five years ago, repairing a home telephone required a visit from a repairman. Today, problems in telephone, Internet, and cable television service are frequently diagnosed and made remotely by Customer Service Associates (CSA) sitting at computers. CSAs need technical knowledge and they need communication skills to work with a customer in diagnosing a problem. Anthony Ashton (not his real name), a Verizon employee who has worked as a CSA, explains:

> *There is a real generation gap. Younger customers know a lot about the Internet. They know about networks, how services are supposed to work. They have spent time trying to figure out the problem before calling us. Older customers may not know the difference between the right click versus the left click on a mouse. I would say 70 % of customers who call in for technical support can't figure out their own equipment.*

When the caller says "my television has no picture," the CSA uses digital readings on a screen and conversation with the customer to visualize the customer's equipment and determine where the failure lies. It may be a problem in the set top box that can be repaired remotely. It may be a problem in a cable linkage that requires a technician visit. It may be a problem in the customer's own equipment in which case communication skills become particularly important. Customers are responsible for their own equipment. Because information is ambiguous, a customer who hears his own equipment is at fault does not know whether the CSA is telling the truth or just passing the buck:

> *In the end, you have to sit there as a CSA and prove to the customer that [Verizon] service is working to the house and it is their equipment or something they are*

> *doing that's causing the problem. There are some things you can do. You can ask if the TV is turned on. If the customer has a DVD or Blue Ray, you can ask them to check whether the input is set to the TV and not to the DVD player. If the DVD is turned on, you can ask whether they see a picture from the DVD. But if the problem is in their equipment, you have to convince them and that's a hard part of the job.* "

Teaching, selling, managing, nursing, reporting—these and many other jobs emphasize communication because their task is to exchange not just information but a *particular understanding* of information.

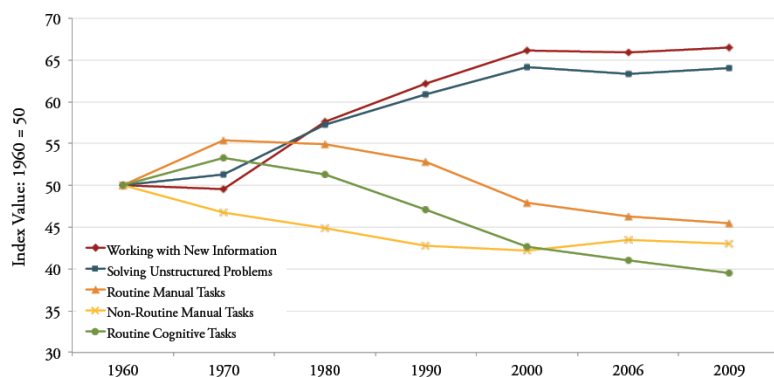### Figure 3: Index of Changing Work Tasks in the U.S. Economy 1960-2009 [21]

Figure 3 shows how the relative importance of the five types of tasks has changed as a result of changes in the U.S. occupational mix since 1960. [20] Human work centering on routine cognitive tasks and routine manual tasks (e.g., filing, assembly line work) has declined steadily since 1970, the result of both computer substitution and the sending of work offshore. Conversely, solving unstructured problems and working with new information—work that is hard to computerize or send offshore—increased steadily between 1970 and 2000 and held steady over the subsequent decade. Because Figure 3 cannot capture task changes within occupations—for example, the changing nature of the secretary's job—it understates the changing nature of work.

The message of Figure 3 is that human work in the U.S. economy increasingly consists of three types of tasks: non-routine manual tasks, solving unstructured problems (car repair), and working with new information (determining a customer's Internet problem). The growing importance of the second and third tasks represents a significant shift. For much of the 20th century a significant amount of work involved following directions. In many situations, directions were a shortcut—a way to accomplish a task without much knowledge of the underlying process. Today, work that consists of following clearly specified directions is increasingly being carried out by computers and workers in lower-wage countries. The remaining jobs that pay enough to support families require a deeper level of knowledge and the skills to apply it.

How Skills are Acquired

When Arthur Edwards was 17, he drove cars but didn't know how cars worked. The knowledge began to come five years later.

> "I started taking auto repair classes at a community college after I received my undergrad degree because I had a 15-year-old Ford van that I couldn't afford to pay anyone else to fix, so I thought I should learn to fix it myself. I can clearly remember seeing some brochures posted on a bulletin board in the college shop and one stated that the median annual income for auto mechanics in Michigan was $40,000 and I thought, "there's a possibility here." And so I decided to approach it professionally rather than as a hobby or necessity."

Once engaged, Arthur learned how cars worked through classroom training, job experience, reading technical bulletins, and conversations with other technicians.

Most people follow this path. They acquire the knowledge and skills used in their work through post-secondary education and training and on-the-job experience. But as economist James Heckman noted, "skills beget skills": the ability to acquire skills at one age depends on skills acquired at earlier ages. Arthur Edwards' ability to acquire job-related knowledge and skills at age 21 rested on foundational skills he had already acquired. He had learned to read carefully and critically and how to make sense of new vocabulary. He knew how to search efficiently for information on the Internet. He could understand mathematical arguments and use mathematics in problem-solving. He could use mental models to think about cause and effect. In part because of his vocabulary, he could communicate well, orally and in writing, so he could learn efficiently from classmates and other mechanics and share his knowledge with others.
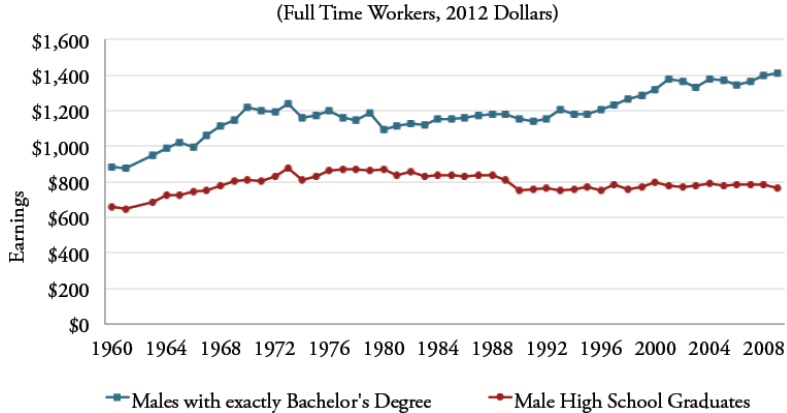
Computerized work has ratcheted up the definition of foundational skills. Consider literacy. Forty years ago, reading well enough to follow directions was sufficient. Today literacy includes conducting an Internet search efficiently and judging what small portion of the thousands of the responses to any query provides useful information. Literacy also includes the ability to make sense of the new information constantly encountered as a person faces new problems.

Computerized work has also made knowledge more abstract and more reliant on data. In the late 1970s, Ford Motor Company began to use computer-controlled fuel injection systems in place of mechanical carburetors. Ford soon experienced heavy warranty expenditures because many technicians, not understanding fuel injection, would tackle a problem by "throwing parts at it"—replacing one component after another in the hope that something would work. Ford responded by requiring that warranty repairs could only be made by technicians who had passed a training course on repairing fuel injection systems. Half of the technicians who took the training course failed, many because they could not read well enough to understand the technical manuals. They knew how to repair mechanical carburetors because they had

watched other mechanics do it. Watching other mechanics could not teach them to use computerized tools to test electronic components.
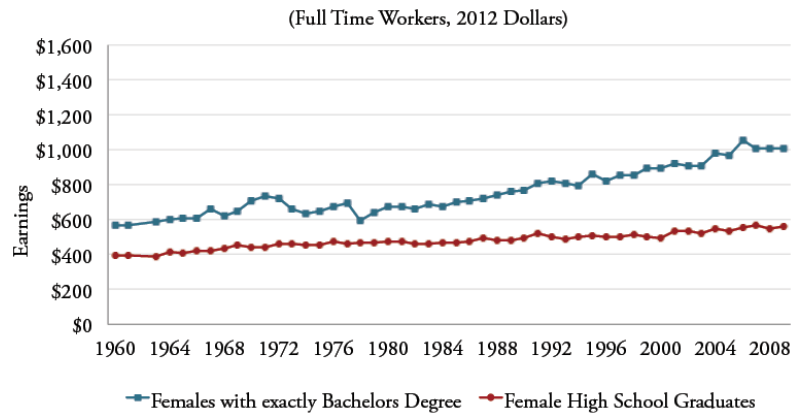
As knowledge has become more abstract, the average person's earnings have become increasingly correlated with educational attainment. In 1980 the average 40-year-old male with a bachelor's degree (BA) and no graduate work had weekly earnings 26% higher than the average 40-year-old male whose education stopped at high school graduation. [22] By 2009 the gap had grown to 84% (Figure 4a). In keeping with the idea that skills beget skills, increased demand for college graduates reflects both what an individual learned in college and the college degree as a signal that an individual possesses sufficiently strong foundational skills to acquire job knowledge efficiently. [23] At the same time the declining demand for workers carrying out routine manual and routine cognitive tasks forced many high school graduates out of assembly-line and clerical work and into lower-paying service occupations. In 2009, the average 40-year-old man with a high school diploma had weekly earnings 12% less, net of inflation, than a comparable man's earnings in 1980.

Figure 4a: Median Weekly Earnings of 35-44 Year Old Men [24]

(Full Time Workers, 2012 Dollars)

Legend: Males with exactly Bachelor's Degree — Male High School Graduates

Figure 4b: Median Weekly Earnings of 35-44 Year Old Women [25]

(Full Time Workers, 2012 Dollars)

Females with exactly Bachelors Degree — Female High School Graduates

The college-high school earnings gap increased almost as rapidly for women as for men, from 42% in 1979 to 78% in 2009 (Figure 4b). In the case of women, however, high school graduates' earnings were rising slowly rather than falling. In 1980, female high-school graduates earned considerably less than males, in part because few women held high-wage jobs in durable manufacturing. Conversely, when these jobs disappeared in the Blue Collar Recession of the early 1980s, relatively few women lost jobs.

An accurate picture of skill acquisition has to go back further to ask how foundational skills themselves are learned. Again, skills beget skills. A student's foundational skills depend on what is learned in formal K-12 schooling, but also on what is learned at home. The impact of family is clearest in vocabulary and background knowledge. In a famous study, Hart and Risley documented that between the ages of one and two, children of parents in professional jobs hear their parents speak an average of eleven million words. By comparison, children of working parents hear their parents speak six million words and children of families on welfare hear their parents speak three million words. [26] While vocabulary gaps existed in earlier decades, these gaps have become much more important in today's labor market. With the constant need to acquire and work with new information, literacy requires not only the ability to sound out words phonetically, but also the background knowledge and vocabulary to make sense of newly encountered words and concepts.

The Education Challenge

From the end of World War II through the 1970s, college graduates earned more than high school graduates, but earnings for both groups were rising in real terms (Figures 4a, b). Male blue collar workers in 1965 earned more, adjusted for inflation, than most managers had earned in the late 1940s. This remarkable period of U.S. economic growth resulted in broad, upward mobility stemming both from increasing educational attainments of successive generations of Americans and from rising real earnings in most occupations.

By the mid-1980s, labor-market demand for workers carrying out routine manual and routine cognitive tasks was declining. The result was a decline in the real earnings of male high school graduates and a slowdown in the rate of wage growth for female high school graduates. [27] While computerized work and offshoring were not the sole causes of the declining opportunities for high school graduates, both factors played an important role. Declining fortunes of high-school educated workers had two important consequences:

- Many people faced downward economic mobility, earning less real income than their parents had earned.

- Education moved from being one source of upward mobility (along with generally rising earnings) to *the main* source of upward mobility.

Both developments increased inequality of children's opportunities and put expanded pressure on schools.

It is likely that falling real earnings for male high school graduates contributed to their declining rates of marriage and family formation. [28] In 1970, a child living with a high school graduate mother and a child living with a college graduate mother had the same chance—nine-in-ten—of living with two parents. In 2008, a child with a college graduate mother still had a nine-in-ten chance of living with two parents. But the chance for a child with a high school graduate mother had fallen to seven-in-ten. One consequence of more female-

headed families was a rising fraction of all children living in poverty: 15% in 1980 to 20% in 2009. Roughly speaking, the spread of computerized work is increasing the importance of education even as it is undermining many children's opportunity to acquire foundational skills needed for post-secondary education. We return to this point later in the paper.

As education became more important, growing up in higher-income, professional families became a particularly large advantage. Higher income families could provide the strong vocabulary and background knowledge described above and they had more money to spend on child enrichment. In the early 1970s, college was not yet viewed as a necessity and families in the top fifth of the income distribution spent an average of $3,700 per year (adjusted for inflation) on activities including summer camps, vacations, college visits, and tutoring. By 2005-6, spending on enrichment by families in the top fifth of the income distribution had almost tripled ($9,400). Low-income families could not match the increase. [29]

Children in higher income families also had a better chance of completing college because of both stronger foundational skills and a greater ability of parents to pay. Among children from the top quarter of the family income distribution, the percentage earning a four-year college degree by the age of 25 increased from 36% for those born in the early- to mid-1960s to 54% for those born in the early 1980s. Among children from the bottom quarter of the family income distribution, BA attainment rose from 5% to 9%. [30]

Historically, the United States relied on public education to level the unequal playing field for children born into different circumstances. This means providing all children with strong foundational skills. The best yardstick of schools' progress in achieving this objective is the National Assessment of Educational Progress (NAEP). The original NAEP reading and mathematics assessments were first administered in the early 1970s and measured foundational skills that were

appropriate for the time. In 1990, NAEP introduced a revised set of assessments measuring students' mastery of an upgraded set of foundational skills including the ability to read critically, make inferences from text, and explain the steps in solving mathematical problems—skills more relevant to today's workplace. [31] To score at the proficient level an eighth grader had to be able to read a 950-word article from the *New York Times' Upfront Magazine*, "1920: Women Get the Vote," and write coherent paragraphs responding to questions like this:

> *The section "Wyoming Is First" describes changes in United States society in the late 1800s and early 1900s. Choose one of these changes and explain its effect on women's progress in getting the vote.*

Figure 5: Percentage of 8th Graders Scoring at Proficient or Advanced in Reading [33]
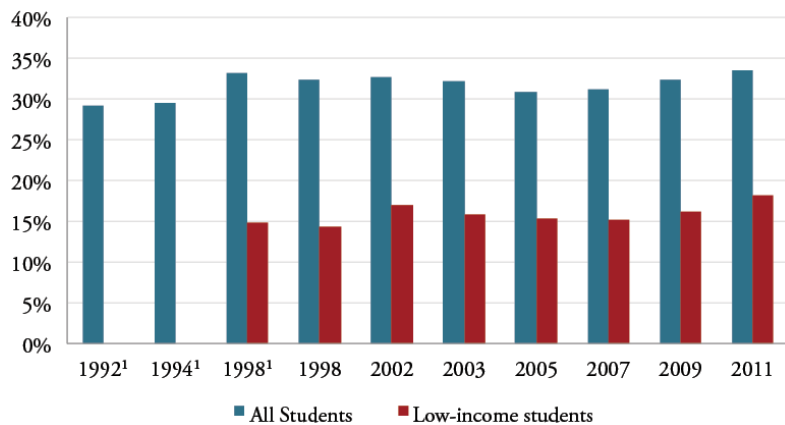
As shown in Figure 5, between 1992 and 2011, the percentage of American 8th graders scoring at the Proficient or Advanced reading level rose five percentage points from 29 to 34 %. [32] This meant that, as of 2011, only one in three American 8th graders and less than one in five 8th graders from low-income families were entering high school as proficient readers.

To be graded as proficient in mathematics, 8th graders had to correctly answer questions like the one below and provide a coherent explanation for their answer:

> *The sum of three numbers is 173. If the smallest number is 23, could the largest number be 62?*
>
> *Yes _____ No _____*
>
> *Explain your answer in the space below.*

While children learn much of their vocabulary from home and environment, children learn most of their mathematics in schools, giving schools more leverage in developing students' mathematics skills. Between 1992 and 2011, the percentage of 8th graders who were proficient or advanced in mathematics rose by twenty percentage points from 15% to 35%, a significant accomplishment. But it is still the case that only about one in three 8th graders enters high school with Proficient mathematical skills, and fewer than one in five students from low-income families does so. [34]

It is important to put these trends in perspective. American schools are not worse than they were in a previous generation. Indeed, the evidence is to the contrary. Results from the NAEP long-term assessments show that most American students now master foundational skills as defined 40 years ago—for example, reading well enough to follow directions. Today's education problem stems from the increased complexity of foundational skills needed in today's economy and from the changes in family income and family structure that leave a significant portion of American children unprepared to learn when they enter school.

If teaching today's foundational skills had only required adding new courses—for example, a class on building communication skills and another on problem-solving—progress as shown on the revised NAEP might have been faster. But teaching today's foundational skills requires

changing how core subjects are taught, with increased emphasis on conceptual understanding and problem-solving. Lacking clear guidance and support for changing instruction, most teachers teach the way they were taught as students—providing what is now an inappropriate focus on mastering the procedural skills needed to carry out routine cognitive and manual tasks.

Over time, the problem of teaching advanced skills has been compounded by the increasing segregation of students by income with large numbers of low-income children concentrated in high poverty schools. A child in a high poverty school faces multiple handicaps in mastering foundational skills: a majority of classmates with weak preschool preparation, students transferring in and out of class during the year, and a low chance of being taught by a stable set of skilled teachers who work together to improve instruction over an extended period of time. [35]

For the last 15 years, the primary strategy for improving public education has been the test-based accountability embodied in state initiatives. These initiatives became national policy with the 2001 passage of *No Child Left Behind* (NCLB). NCLB was designed to both focus attention on all students' academic skills and to impose sanctions on schools in which the percentage of students achieving proficiency on reading and mathematics tests did not increase over time. In keeping with the decentralized structure of U.S. education, NCLB let each state choose the academic standards students should master, the tests to assess students' skills, the minimum scores required for proficiency, and the level of investments made to improve teaching and learning.

The available evidence indicates that NCLB had, at best, a modest positive effect on reading and math scores in some grades as measured on national tests. [36] NCLB also created incentives for states to choose relatively undemanding tests and set low proficiency thresholds, a process that undermined the legislation's purpose. [37] These responses are evident in comparisons of NAEP 8th grade proficiency

standards and those chosen by states. The NAEP defines three levels of reading skill: Advanced, Proficient, and Basic. Proficiency on the NAEP 8th grade reading assessment corresponds to a minimum scale score of 281. Among the states, Missouri has the highest proficiency standard that corresponds to a NAEP scale score of 261. Seventeen states define proficiency using a standard below the NAEP standard for Basic understanding. [38]

The recent development of Common Core State Standards (CCSSs) responds to this problem and holds significant promise for improving American education. These standards represent the best thinking on the literacy and mathematics skills that students are expected to master at each grade level. Equally important, they have been adopted by 45 states reflecting cooperation that few observers would have thought possible thirty years ago. Complementing the standards, two consortia of states are developing assessments to measure students' mastery of these skills.

If successfully implemented, the CCSS standards can give teachers and school administrators clarity on the foundational skills students need. CCSS assessments can provide rich evidence on students' progress in mastering those skills. These would be the first steps in a long process that includes aligning curricula to the CCSS and improving both teacher training and professional development for current teachers.

Despite its potential, implementation of the CCSS carries significant risks. In states currently using weak accountability standards, the switch to CCSS assessments will show declines in student proficiency and increases in achievement gaps between low- and high-income students. [39] One result will be political pressure in many states to drop the CCSS, a decision with far-reaching costs, but costs that will only become apparent when students attempt to pursue post-secondary education or are looking for jobs paying decent wages.

Computers, Mobility, and National Institutions

Computerized work has increased the complexity of the foundational skills Americans need to thrive in a changing economy. Simultaneously, it has created economic dislocations that have left many families without the resources to make big investments in their children. Taken by themselves, these two effects are a recipe for an increasingly class-bound society with little upward mobility. That threat is real: recall that a child born in the top quarter of the income distribution is about six times as likely to earn a Bachelor's degree by age 25 as a child born in the bottom quarter. But attributing this pattern entirely to computers gives computers a larger role than they deserve.

Computerized work does not advance in a vacuum. Its impact on a nation depends in part on the nation's institutions: the way that wages are determined, the nation's tax system, the safety net for displaced workers and families, the cost and quality of a college education, the provision and quality of preschool education.

Consider four countries—the U.S., the United Kingdom, Norway, and Denmark. Each country is exposed to computerized work and offshoring yet their levels of intergenerational economic mobility differ sharply. The correlation between a father's and son's income is 0.09 in Denmark, .14 in Norway, .20 in the United Kingdom, and .38 in the United States. [40] Other international comparisons of economic mobility also point to a low U.S. ranking. [41]

When countries are compared on the income share of the top 1% of households, a similar pattern emerges. In 2010, the top 1% of households received roughly 20% of all income in the United States, 13% in Canada, 12% in Germany (2007), 11% in Japan, and 8% in both Australia and Sweden. [42]

International differences in mobility and inequality reflect more than differences in national institutions. Population, industrial structure, and national culture are all important.

But the cross-country comparisons indicate that today's low levels of U.S. economic mobility and high income inequality are not the inevitable result of computerized work. Rather, they also arise from the political decisions we are making. [43]

Dancing with Robots

We cannot predict with accuracy the occupations that will grow fastest in the future or the precise tasks that humans will perform. Nonetheless, it is a safe bet that the human labor market will center on three kinds of work: solving unstructured problems, working with new information, and carrying out non-routine manual tasks. The rest will be done by computers and low wage workers abroad. It is also a safe bet that most Americans will need to acquire new knowledge and skills over their work lives in order to earn a good living in a changing work world. In this context, the nation's challenge is to sharply increase the fraction of American children with the foundational skills needed to develop job-relevant knowledge and to learn efficiently over a lifetime.

Meeting the challenge would address multiple problems. Through much of the 20th century, successive generations of Americans had substantially higher educational attainments, and rapidly rising education levels were an important contributor to national economic growth. Since the mid-1970s, and despite the high rate of return to schooling, the educational attainments of successive generations have grown much more slowly. A serious commitment to dramatically increasing the percentage of American youth who master today's foundational skills would begin to address this problem. It would also increase the potential for upward economic mobility among children growing up in low-income families.

Finally, we noted earlier that occupational projections show rapid growth in high end jobs, but they also show rapid growth in low paying jobs carrying out non-routine manual tasks—for example, healthcare support occupations that require little formal education. Like any outcome in the labor

market, these projections represent the interaction of supply and demand. The large number of persons without strong skills who can only compete for jobs like these holds down their wages. As skill levels rise, people's opportunities expand and healthcare support and similar occupations will have to pay more to attract the persons they need. This would moderate the inequality in earnings that has increased so dramatically in recent decades. At the same time, the high turnover in these occupations creates openings for front-line supervisors. Workers in service occupations who possess foundational skills are in a much better position to compete for these higher-paying jobs because they can succeed in the training that typically accompanies them. These arguments do not mean that improving American education will solve all of America's problems of growth and inequality, but they are a necessary component of a solution.

We close with three guidelines for providing all American children with today's foundational skills. First, it is important to begin closing the large income-based gaps in cognitive and socio-emotional skills that are present when children enter kindergarten as five-year olds. [44] Recent research shows that high quality pre-school programs can close much of these gaps and that income-support programs such as the Earned Income Tax Credit also contribute to the achievement of young children. [45]

Second, it is important to recognize the potential value of the Common Core State Standards (CCSS) in English language arts and mathematics. These parsimonious standards give greater weight to today's foundational skills than the weight given by most state standards. Adoption of the CCSS by 45 states acknowledges the reality that proficiency in mathematics and English language arts should mean the same thing in Mississippi and in Maine. Maintaining the commitment to the CCSS will be difficult politically when results of assessments show greater income- and race-based gaps in mastery of the CCSS than assessments based on current state standards. But even in this period of austerity, long-term investment to close these gaps is a necessary

condition for reversing the growth in family income inequality that jeopardizes the American commitment to upward socio-economic mobility. One early indicator of progress will be a reversal of the current situation in which children most in need of the nation's best teachers are the least likely to get them.

Finally, while all American teenagers need to master foundational skills, different students will need different secondary school experiences to accomplish this objective. For some, academic curricula explicitly focused on preparation for post-secondary education will work best. For others, learning is better done through career and technical education (CTE) that provides more explicit links between foundational skills and groups of occupations. Indeed, one of the unexpected findings of recent research has been that students engaged in well-designed CTE programs fare at least as well on state-mandated examinations of mathematics and English as similar students studying more traditional academic curricula. [46] A variety of well-designed secondary school options will be needed if America is to return to the position it held in the late 1960s as the member of the OECD with the highest high school graduation rate.

Advances in computerization are having profound impacts on life in America. Many of the impacts are positive—most Americans enjoy the new products and services that are fruits of technological advances. But technological change has also created tremendous dislocations in labor markets, especially the elimination of routine cognitive and routine manual tasks that provided work for generations of high school graduates. These changes will continue in the foreseeable future, increasing the importance of providing all American children and youth with foundational skills needed to prepare for jobs in well-paying expanding occupations. The extent to which the country makes progress in accomplishing this will determine to a large extent whether the American dream of upward socioeconomic mobility is part of the nation's future and not just part of its past.

About the Authors

Frank Levy is a Daniel Rose Professor Emeritus at MIT and a Lecturer at the Department of Health Care Policy, Harvard Medical School. He studies the impact of technology on the content of work, wage levels and income inequality. In 2002 and 2003, two papers co-authored with David Autor and Richard Murnane characterized the kinds of workplace tasks that computers would replace. His 2005 book, *The New Division of Labor*, co-authored with Murnane, described the impact of computers and offshoring on available jobs in the economy and the skills those jobs require.

Levy's more recent work includes papers on the (non-) offshoring of medical imaging (co-authored with Ari Goelman and Kyoung-Hee Yu) an examination of the declining role of political institutions in reducing income inequality (with Peter Temin) and an explanation of the recent slowdown in the rapid growth of medical imaging costs (with David Lee).

Work in progress includes examining the economic payoff to a Bachelor's degree in the University of California and California State University systems (with Alan Benson and Raimundo Esteva) and book describing the "medical bubble" traced by radiology from the early 1990s through the present (with Max Rosen).

Selected papers are available on Levy's homepage.

Richard Murnane is the Thompson Professor of Education and Society at the Harvard Graduate School of Education and a Research Associate at the National Bureau of Economic Research. His research focuses on how computer-based technological change has affected skill demands in the U.S. economy, how increases in family income inequality in the U.S. have influenced educational opportunities for children from low-income families, and the consequences of policies aimed at improving education. He has written two books with Frank Levy related to the topic of this paper.

Murnane's recent papers include "U.S. High School Graduation Rates: Patterns and Explanations." The *Journal of Economic Literature* (June 2013); "Literacy Challenges for the Twenty-First Century: Introducing the Issue," (with Catherine Snow and Isabel Sawhill) The Future of Children (Fall 2012); "Extending the regression-discontinuity approach to multiple assignment variables," (with John P. Papay and John B. Willett), *Journal of Econometrics* (April 2011); "Do Financial Incentives Help Low-Performing Schools Attract and Keep Academically Talented Teachers? Evidence from California," (with Jennifer L. Steele and John B. Willett) *Journal of Policy Analysis and Management* (June 2010).

In 2011, Murnane co-edited (with Greg Duncan) *Whither Opportunity? Rising Inequality, Schools, and Children's Life Chances*. (New York: Russell Sage). In January 2014, Harvard Education Press will publish Murnane and Duncan's book, *Restoring Opportunity: The Crisis of Inequality and the Challenge for American Education*.