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ICT, Education Transformation, and Economic Development: an analysis of the US National Educational Technology Plan

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ABSTRACT In support of the conclusions and recommendations in the National Education Technology Plan (NETP), this article makes explicit the connections between the economic rationale used in the plan and the educational transformations it recommends. The article reviews macroeconomic research, microeconomic research, labor market and workforce studies, and studies showing patterns of the everyday information communication technology (ICT) use in American life to document the profound changes occurring in the American economy and society. It also reviews studies showing a gap between what is happening in American schools and the experiences and skills that our youth need to enter the information economy. The article concludes with an analysis of and an elaboration on the transformational recommendations made in the NETP, based on these reviews.

In March 2010, the US Department of Education (Office of Educational Technology, 2010) released a draft of the National Educational Technology Plan (NETP) to advance the educational reform goals of the Obama administration. An explicit premise of the NETP, and of the Administration's educational goals more generally, is that 'education is the key to economic growth and prosperity and to our ability to compete in the global economy' and that education 'is the path to good jobs and higher earning power for Americans' (p. v).

Citing this economic rationale, the NETP calls for a transformation of American education. With a backdrop of high unemployment and the worst recession since the Great Depression, the economic rationale has a particular saliency and the call a particular urgency. The plan goes on to review research literature in education and the learning sciences and it makes recommendations for the use of technology to support the transformation of the US education system. Information communication technology (ICT) recommendations are made about the availability and access of all teachers and students to broadband connectivity, Internet devices, software, and digital resources for research, communication, content creation, and collaboration. But the plan does not limit itself to infrastructure considerations. A particular strength of the NETP is that infrastructure recommendations are made as part of a constellation of coordinated recommendations related to other components of the education system, such as curriculum, pedagogical practices, assessment, teacher professional development, and school organization.

In support of the conclusions and recommendations in the NETP, this article makes explicit the connections between the economic rationale used and the transformations recommended by the plan. It reviews a different body of research than that cited by the NETP to describe the tectonic shifts occurring in the US economy and society – much of it propelled by advances in ICT – and to elaborate on the growing gap between the processes and outcomes of our current education system and the requirements of the nation's economy and society. As the plan contends, there is an urgent need to change US education and close this gap, if the US is going to continue to be competitive in the global economy and retain its leadership role in the world.

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Five sorts of research are reviewed in this article:

- Macroeconomic research showing that over the past several decades the US and global economies have undergone a fundamental shift from a manufacturing economy to an information economy, much of it driven by ICT.
- Microeconomic research showing that individual firms are undergoing significant changes in organizational structure and business practices, much of it facilitated by the pervasive presence of ICT in the workplace.
- Labor market and workforce studies showing a significant shift in the kinds of jobs and skills that are needed by our economy, skills that are intimately connected to the use of ICT.
- Studies showing patterns of the everyday ICT use in American life, particularly use by young Americans, patterns that are closer to the use of ICT in the business world than to that in schools.
- Studies showing that American schools are not using ICT in a significant way or providing youth with the experiences and skills they need to enter the information economy.

The article will conclude with an analysis of and an elaboration on the transformational recommendations made in the NETP, based on these reviews.

Macroeconomic Trends: shifting from manufacturing to information economy

Macroeconomic studies – those that look at entire economies – show that the US economy has undergone profound changes over the past several decades. These changes have significant implications for how people work, live, and play and, most certainly, implications for education: for what is taught, how it is learned, and how schools are organized. Many of these changes have been fostered by the dramatic growth in information communication technologies.

In the American economy of 1950, construction and the manufacture of material goods (such as automobiles, chemicals, and industrial equipment), along with the delivery of material services (such as transportation, retailing, and utilities), accounted for nearly 56% of the country's gross domestic product (GDP), according to Bureau of Economic Analysis (BEA) statistics [1], as shown in Figure 1. Figure 2 shows that a majority of the nation's workforce – 57% – was employed in these sectors, 32% in manufacturing and construction alone.

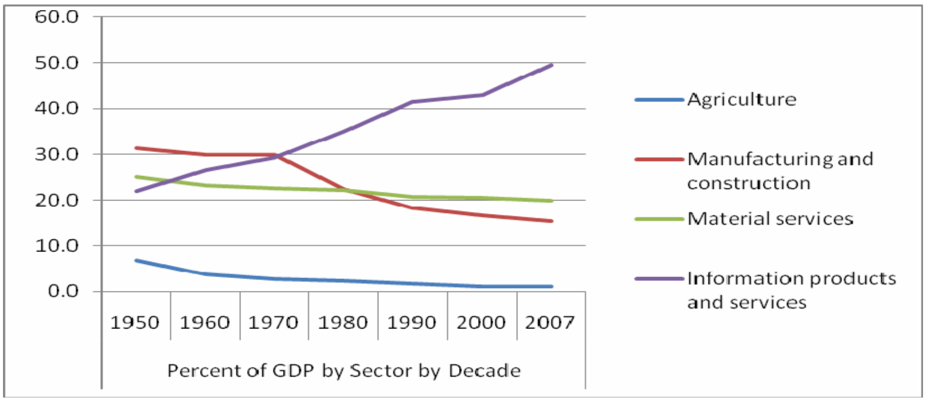

Figure 1. Percent of gross domestic product by sector.

However, by 1990, manufactured goods and material services had dropped to 39% of GDP, employing only 43% of the nation's workforce. The most recent year for BEA figures is 2007, prior to the recent recession. That year, material goods and services accounted for only 35% of economic output and 40% of jobs. Only 14% of all those employed were in manufacturing and construction, less than half the percentage in 1950. In 2007, a worldwide recession began. From the last quarter of 2007 to the first quarter of 2009, the US economy shrank by nearly 4%, dropping by $514 billion in output.[2] The economy shed 7.2 million jobs and the jobless rate reached 10% (Lahart, 2010). While job loss cut across sectors, it hit construction and manufacturing particularly hard: 1.6

million jobs were lost in construction during the two years, and since 1997, 6 million jobs were lost in manufacturing.

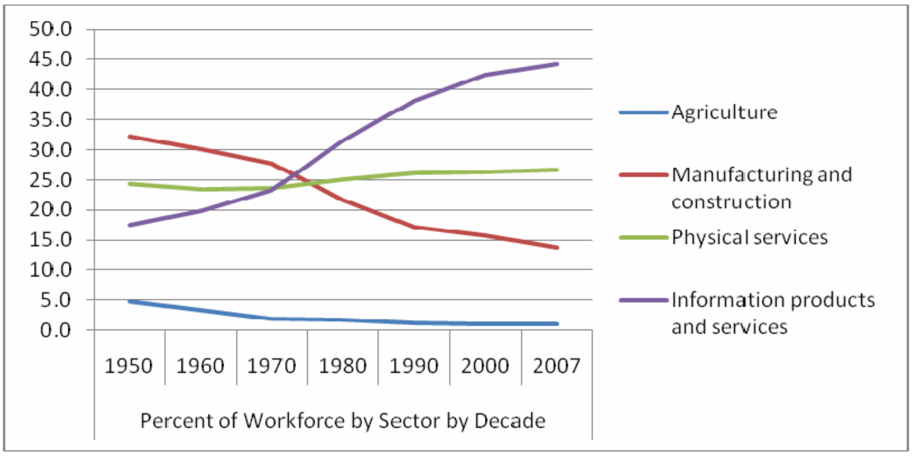

Figure 2. Percent of workforce by sector.

As dramatic as this shift is, it is only half of the story. By 1980, the production of information products (such as computers, books, televisions, and software) and the provision of information services (such as financial services, entertainment, health, and education) came to account for 35% of the country's output, surpassing manufacturing and construction, which had come to account for only 22% of the output. By 2007, information products and services grew to account for 50% of the economy and 44% of employment.

Some economists using more sensitive accounting attribute an even higher proportion of the US economy to these sectors. Karmarkar & Apte (Karmarkar & Apte, 2007; Apte et al, 2008) figured that by 1997, the production of information products and the provision of information services accounted for 63% of the country's output. Information services alone accounted for 56% of the economy. Karmarkar & Apte also document that information services accounted for the largest portion of the nation's wage bill - 48%, compared with 38% for non-information service workers. That is, as a group, information workers are paid better than those in material products and services. There is more than $10,000 difference between information service providers and material service providers, and the wage gap between workers in the information products sector and those in the material products sector is more than $20,000. By comparison, the information products and service sectors have done well in the recession. At a time of massive layoffs in construction and manufacturing, there were 3 million job openings that were unfilled in February of 2009 (Coy, 2009). The highest number of vacancies was in the information sector, in areas like education, health care, and business professions and services. This trend is expected to continue as the country comes out of the recession. While construction, manufacturing and physical services are expected to add 1.3 million jobs to the economy between 2008 and 2018, information services are expected to add 13.3 million jobs, based on Bureau of Labor Statistics projections.[3]

The climax of these trends came in 2009, when two of the 'Big Three' US auto makers, icons of the manufacturing economy, declared bankruptcy and the third teetered on the edge. But while GM and Chrysler are in bankruptcy court and Ford was valued at a meager $43 billion, Apple was valued at $237 billion and the combined value of Apple, Microsoft, ATT, Cisco, Intel, and Google was over $1 trillion.[4] This set of events, more than any other, confirmed a shift from an economy based primarily on making and consuming things to one primarily based on creating and using information.

If educational technology policy, or education reform policy more generally, is going to contribute to economic growth and prosperity, prepare Americans to compete in the global economy, and provide them with a path to good jobs and higher earning power, it must acknowledge this new reality and be coordinated with economic policies that develop a highly competitive information economy and knowledge society in America.

Microeconomic Trends: changes in business organization and practices

ICT has contributed to economic change not just through the growth of the information products and services sectors. It has also fostered fundamental changes in how business is done across a range of economic sectors. Microeconomic studies – those that look at individual firms – confirm the impact of ICT on business practice. First, these studies show that the use of ICT has supported a significant surge in US productivity. Stiroh (2003) analyzed aggregate productivity data for 1987-1995 to 1995-1999 for three sets of US industries: ICT-producing industries, ICT-using industries, and other industries. ICT-producing industries showed a mean productivity acceleration of 3.7 percentage points; ICT-using industries posted an increase of 2.0 percentage points; all other industries showed an average gain of only 0.4 percentage points.

Black & Lynch (2004) analyzed the causal mechanisms behind the connection between ICT use and productivity. They looked at computer use in the workplace along with a number of other business practices in a sample of US industries. They found that significant firm-level productivity increases were associated with changes in business practices that included re-engineering, regular employee meetings, the use of self-managed teams, up-skilling of employees and the use of computers by front-line workers. A large number of studies have corroborated Black & Lynch's conclusions and found that the success of highly productive, innovative firms is associated with the use of ICT as part of a constellation of mutually reinforcing organizational structures and business practices that work together as a coherent system (Gera & Gu, 2004; Pilat, 2004). For example, Murphy (2002) found productivity gains in US companies when the use of ICT was accompanied by changes in production processes (quality management, lean production, business re-engineering), management approaches (teamwork, training, flexible work and compensation), and external relations (outsourcing, customer relations, networking). In Canada, Zohgi et al (2007) found a strong positive relationship between both information sharing and decentralized decision making and a company's innovativeness. Similar patterns were found in the UK (Borghans & ter Weel, 2001; Dickerson & Green, 2004; Crespi & Pianta, 2008), France (Askenazy et al, 2002; Maurin & Thesmar, 2004), Finland (Leiponen, 2005), Japan (Nonaka & Takeuchi, 1995), and Switzerland (Arvanitis, 2005). In other words, productivity increases come by using ICT not just to improve previous business practices but to change how business is done – by using it to flatten organizations, increase participatory decision making, support flexible work arrangements, and foster information sharing and collaboration within, across, and between organizations.

Researchers and journalists (Johnson et al, 2005; Manyika et al, 2007; Bughin et al, 2008; Tapscott & Williams, 2008; Billington & Davidson, 2010) are beginning to provide the details of how ICT is enabling the collaboration and coordination of workers within companies distributed across divisions or locations, or between companies and their partners and suppliers, and even between companies and their customers. For example, Wal-Mart uses ICT to track goods, trade information with suppliers, and forecast demand (Johnson et al, 2005). The health care provider Kaiser Premanente uses its internal network and unified digital records on its patients to track the schedules of caregivers, schedule appointments, share patient information across caregivers, and track treatment effectiveness. Google fosters innovation in its company through an internal market of ideas where employees submit proposals for new products or services on an internal network and other employees decide whether the idea is worth pursuing or whether they would be willing to work on it full time. A range of manufacturers, from HP and Apple to Boeing, are relying on a network of partners, distributed around the world, to design and produce hundreds of parts for their products that fit together seamlessly when assembled (Bughin et al, 2008). The operating system Linux, used by eight of the ten most reliable Internet hosting companies, and the open-source Web-server Apache, which runs more than half of all websites, were both incrementally and collaboratively created by an ad hoc set of contributing programmers from around the world. A global team of more than 2000 scientists, in 165 working groups distributed around the world, contributed to the design of the ATLAS particle detector, a complex scientific instrument used to detect and measure subatomic particles in high-energy physics. Toy manufacturer LEGO and the shirt retailer Threadless are using ICT to enlist their customers in the co-creation of new products. Auto maker Peugeot invited people to submit car designs online, and it built a demonstration model of the winning design to exhibit at automotive marketing events. As a result of networked collaboration, companies are identifying and solving problems, improving services, and creating new products.

This shift in business operations away from a top-down, command-and-control organizational model characteristic of the manufacturing economy and towards the technologically connected and empowered participation and collaboration of employees, partners, and customers has profound implications for the value of human capital, relative to physical capital, and for the importance of a highly educated, technically skilled, and creative workforce. Education policies and pedagogical practices that emulate and perpetuate the top-down, command-and-control, social and business paradigm do not empower students or prepare them for a highly distributed and collaborative environment in which they will live during the twenty-first century.

Labor Market Trends: need for a different skill set

As intimated above, the restructuring of the economy, the reorganization of work, and the uptake of ICT have corresponded to a need for increased education and skill on the part of the labor force. A study by Carnevale & Desrochers (2002) found a significant increase in the number of workers in the US economy who have at least some level of higher education. Between 1973 and 2000, the percentage of US workers with some post-secondary education increased from 28% to 59%, and the proportion with bachelor's degrees increased from 9% to 20% during that period. In terms of demand, this upward trend looks likely to continue. The Bureau of Labor Statistics predicts that those occupational categories that require a postsecondary degree will experience the most rapid growth between 2008 and 2018.[5]

But it is not just the amount of education and the need for it that is changing. The new economy requires an additional set of skills, particularly those related to the use of ICT. Autor, Levy & Murnane (Autor et al, 2003; Levy & Murnane, 2005; Autor, 2010) analyzed a range of labor tasks in the workplace. They found that, commencing in the 1970s, manual tasks in the US economy declined, reflecting the macroeconomic shifts away from manufacturing described by Karmarkar & Apte (Karmarkar & Apte, 2007; Apte et al, 2008). Interestingly, the Autor et al studies also found a drop in routine cognitive tasks – such as maintaining expense reports, filing insurance claims, and evaluating mortgage applications. They found that as ICT was taken up by firms, computers substituted both for workers who performed routine physical tasks and for those performing simple cognitive tasks because these repetitive, predictable tasks could be readily automated. On the other hand, non-routine analytic and interactive tasks increased. These are tasks such as diagnosing uncommon illnesses, motivating employees, creating a good-tasting, nutritious dish, and explaining complex concepts. This finding was particularly pronounced for rapidly computerizing industries, and it confirms the impact that ICT is having on the nature of work in the new economy. While ICT is substituting for workers who perform routine physical and cognitive tasks, it complements workers who perform non-routine problem-solving tasks – technological tools and digital resources help them make better decisions. Consequently, computerization of the workplace has increased demand for problem-solving and communications skills, such as responding to discrepancies, improving production processes and coordinating and managing the activities of others, and for technology skills.

The net effect is that companies in the United States are hiring workers with a higher skill set. In a recent survey of over 2000 managers and executives by the American Management Association (2010), a majority of respondents agreed or strongly agreed that when considering new hires, they make an effort to assess critical thinking skills (76%), communication skills (81%), collaboration and team-building skills (61%), and creativity and innovation (60%); 76% felt that these skills would become even more important over the next three to five years, as the country comes out of the recession. When asked why they thought these skills were important, 91% of the respondents felt that it was because of the rate of change in business, 86% said it was because of global competitiveness, and 78% said it was because of how work is accomplished today. The need for these skills is likely to increase as the economy comes out of the recession.

It is now clear that with the widespread use of ICT, the memorization of facts and the implementation of simple procedures have become less important in the twenty-first-century information economy. Crucial is the ability to respond flexibly to complex problems, to communicate effectively, to manage information, to work in teams, to use technology, and to produce new knowledge. These capabilities have come to be called '21st century skills' (Partnership for the 21st Century, 2005; ISTE, 2007; Trilling & Fadel, 2009). Education policies that perpetuate a curriculum and assessments based on the memorization of facts and the solution of simple one-step problems and pedagogical practices that emphasize information transmission and drill and practice will not provide students with skills that they need for high-value, globally competitive twenty-first-century jobs.

Social Trends: everyday ICT practices

In addition to its economic impact, the pervasiveness of ICT across the country has had a significant social impact on America, such that people access, use, and create information and knowledge very differently than they did in previous decades – they are living in what is sometimes called the 'knowledge society' (Mokyr, 2002). A recent study by the Pew Internet and American Life project (Kennedy et al, 2008) found that more than three-quarters (77%) of all US households own at least one computer, and among households with children, 93% own a computer. A recent study using US Census Bureau data (NTIA, 2010) found that 68.7% of US households have Internet access, and 63.5% of them have broadband access. However, broadband home use is correlated with a number of demographic characteristics: higher-income households, White and Asian Americans, urban residents, and those with higher education levels are much more likely to have and use broadband at home than lower-income households, Black and Hispanic Americans, rural residents, and those with lower levels of educational attainment. This gap remains a significant social issue in the United States, as noted by Warschauer & Martuchniak (2010).

In a national survey, Rainie (2010) found that 74% of US adults use the Internet for various purposes. Another study (Fallows, 2008) found that 60% of American Internet users use it for email, 39% to check the news, 30% to check weather, and 13% for social networking. Nearly half (49%) of Internet users have used a search engine. Indeed, the Internet has become the most commonly used information resource across a variety of topics, such as health, education, taxes, and jobs (Estabrook & Rainie, 2007). The Internet was cited as an information source by 58% of adults, compared with using experts (53%), friends or family members (45%), newspapers (36%), TV or radio (16%), or the public library (13%). Americans use the Internet to shop online; 66% of Internet users have bought at least one product or service online (Horrigan, 2008). And they use it to access video materials; 48% of Internet users have visited a video-sharing site, with 22% shooting their own video and 14% posting their videos online (Rainie, 2008).

Corresponding to findings in the previous section, the Internet has greatly influenced the everyday lives of working Americans. Among employed adults, 86% use the Internet or email, and 62% use the Internet or email at their work (Madden & Jones, 2008). Among those who use the Internet or email, 80% say that these technologies have improved their ability to do their job, 73% say that they have improved their ability to share ideas with colleagues, and 58% say that they have made their work more flexible.

Another recent Pew study (Smith, 2010) found that 59% of all Americans go online wirelessly, 47% via their laptops and 40% with their cell phones. Of the eight in ten (82%) adults who own a cell phone, 76% use it to take digital photos, 72% send or receive text messages, 54% have sent a photo or video, 34% play games, 33% play music, 34% have recorded a video, 23% have accessed a social networking site, and 15% have posted a photo or video online. More than a third (38%) use their cell phone to access the Internet. It is significant that minorities are well-represented among the wirelessly connected. Black Americans and Hispanic Americans are more likely to own a cell phone than White Americans: 87%, 87%, and 80%, respectively. And minorities use these devices to connect to the Internet; 64% of Blacks and 63% of Hispanics connect this way. Young adults (ages 18 to 27) are the most likely to be wirelessly connected. Fully 70% of young adults own a laptop and 95% own a cell phone. Of cell phone owners, 95% use them to send or receive text messages, 93% take pictures, 65% access the Internet, 64% play music, 52% access email, 48% use a social networking site, 33% post their photos or videos online, and 20% make purchases online.

Another Pew study (Lenhart et al, 2010) elaborates on these findings and extends them to younger teenagers (12 to 17 years of age). This study found that 93% of younger teens go online, 63% of them do so every day; 62% of online teens get their information about news or politics online; 48% have bought things online; and 31% get information about health, diet, or fitness online.

Significantly, young people are also heavy creators of media content (Lenhart, Madden et al, 2007). Among online teens, 12 to 17 years old, 64% have created some form of Internet content; 59% of all teens have done so. Among online teens, 33% have created a web page or blog for others, 28% have created their own online journal, and 39% share their own online creations, such as artwork, photos, stories, and videos. Older teenage girls are disproportionately represented among these content producers. Online teens are also heavy social media users (Lenhart et al, 2010). Among online teens, 73% have created a personal profile on a social media site, such as Facebook or MySpace.

All of these studies show that Americans, particularly American youth, have become experienced and highly skilled technology users. This skill is a tremendous human capital resource, as the United States continues to shift toward an information economy and knowledge society. Indeed, for many adults, the use of technology has become a central part of the way they do their work. And certainly it is an integral part of life for American youth. Educational policies that marginalize the use of technology or limit or even forbid the use of personal digital devices and social media fail to take advantage of the tremendous range of experiences, skills, and resources that students bring with them to school.

Educational Trends: the current state of US education

Given the massive changes in the economy and society, the significant technological resources available in American homes, and the impressive technological skills and experiences that young people bring with them to school, how well are schools preparing our youth for the information economy and knowledge society that they will live in during the twenty-first century? The answer is, not well at all.

There has not always been a disconnection between our education system and our economic and social needs. Historically, education has played a crucial role in our country's economic development and social progress. By the beginning of the twentieth century, as the country was moving away from an agrarian society and economic model, elementary education had become universally available (Goldin, 2006). Early in that century, as the mass-production economy began to take root, the number of public high schools grew dramatically. It was also in the early 1900s that schooling as we know it today came to be defined and standardized into what Tyack & Cuban (1995) call the 'school grammar', or the common-sense notion of how 'real school' is structured and organized. This notion was formalized in 1905 by the Carnegie Foundation for the Advancement of Teaching, which specified the characteristics of a 'standard' high school as one that organized time and curricula in terms of Carnegie Units. A Carnegie Unit was a course of five periods, commonly of 55 minutes, offered weekly throughout the academic year. To qualify for college admission, a student would have had to complete a curriculum of fourteen of these units in different subject areas that included English, mathematics, science, history, and foreign languages. This effort created a structure of schooling in the United States that persists more than 100 years later.

This model served the economy and society well for much of the twentieth century. Throughout the century, education enrollment ratios increased at all educational levels. The percentage of youth between the ages of 5 and 19 enrolled in school increased from 51% in 1900 to 75% in 1940 (Snyder, 1993). By the late 1940s, the enrollment rate for 7- to 13-year-olds reached 99%. During the 1950s, the enrollment rate of 14- to 17-year-olds went from 83% to 90%, and to 96% by the late 1980s. Post-secondary enrollment rates increased as well. In 1950, only 30% of the 18- and 19-year-olds were enrolled in school, compared with 60% in 1991. The enrollment rate for 20- to 24-year-olds rose from 9% in 1950 to 30% in 1990.

Increased school enrollment was tightly connected to economic productivity, although the causality of this relationship is not unidirectional. Enrollments both benefit from and contribute to economic development in a virtuous cycle (Birdsall et al, 1995). The more educated the workforce, the more productive the economy, and as the economy grows more prosperous, the more people are able to continue their education. All evidence indicates that the contribution of schooling to growth is a powerful one. A macroeconomic study of a sample of OECD and poor countries (Barro, 2001) found an additional 0.44% growth in a country's per capita GDP for each additional average year of attained schooling – a return on investment of 7%. Other studies have found returns to increased enrollments that go as high as 12% (Sianesi & Van Reenen, 2002; Stevens & Weale, 2003). The quality of education has an even stronger relationship to growth than does the duration of school participation; the amount learned is more important than the number of years of schooling. In a multinational study, Hanushek & Woessmann (2009) found strong, independent relationships between increases in both basic literacy and higher cognitive skills and a nation's increases in economic performance. Similarly, Zagler & Zanzottera (in press) found that an increase of 10% in those scoring at the 95 percentile on an international science test predicted a 1.5% higher rate of growth in a country's economy.

However, with both quantity and quality of education associated with economic performance, the future of our country looks bleak. At a time when a college degree or even advanced levels of education are becoming increasingly important, only about one-third of our young people receive a college degree; a graduation rate that was among the world's highest has dropped to 36%, and the United States is ranked 16 out of 29 developed countries (OECD, 2009). Only about 70% of our young people complete high school, a figure that ranks the United States at 18 out among 22 developed countries.

The quality of US schools has fared no better. As early as 1983, 'A Nation at Risk' expressed a concern about a 'rising tide of mediocrity'. In 1989, President George H.W. Bush and fifty state governors set a national goal of being first in the world in science and math by the year 2000. However, international data indicate that our national educational policies have been a failure in this regard. On the 2000 PISA international assessment, US students ranked 20 out of 41 countries on the mathematics assessment and 15 out of 41 countries in science (OECD, 2003). In contrast to the stated goal of becoming first in the world, US students dropped to 29th among the 40 countries participating in the most recently published PISA science assessment, and 35th out of 40 in PISA math assessment (OECD, 2007).

The future looks particularly bleak for our nation's minority students (Berliner, 2006; Darling-Hammond, 2010). In terms of high school graduation, only about 51% of African American high school-age youth and 52% of Hispanic youth graduate from high school, compared with 72% of White youth (Barton, 2005). And at the college level, only about 19% of African American young people between 25 and 29 and about 12% of Hispanic youth earned a college degree, compared with 37% of the White youth, according to US Census Bureau figures.[6] The gap exists on measures of quality, too. For example, on the 2009 Mathematics National Assessment of Educational Progress, African American students scored 26 points below White students out of 500 possible points, while Hispanic students scored 21 points lower, a gap that has persisted over the past two decades (IES, 2010).

The economic ramifications of this gap are elaborated by the consulting firm McKinsey and Company (Auguste et al, 2009), which created an economic model that mapped the nation's educational performance onto economic performance. It reported that if in 1998 the gap had closed so that African American and Hispanic students were performing as well as White students, the US economy would have generated an addition $525 billion in 2008. The economic impact of the international performance gap is even more profound. If this gap had closed by 1998 so that US students performed as well as their high-performing counterparts in Finland and South Korea, the US economy would have generated between $1.3 and $2.3 trillion more in 2008.

In the face of this atrocious performance, the question of ICT use in schools may seem incidental. But it is the use of ICT, along with other changes in business structure and practice, that is transforming the nation's economy. Yet, the US education data indicate that ICT plays a peripheral role in American classrooms and schools.

On the one hand, it is clear that there has been a significant investment in ICT by the American educational system. By 2005, nearly 100% of public schools in the United States had access to the Internet, and 94% of instructional rooms in these schools had Internet access (NCES, 2006). Broadband availability is almost universal – by 2005, 97% of public school had broadband access. In that year, the ratio of pupils to instructional computers in public schools was 3.8 to 1, meaning there were nearly 13 million instructional computers in public schools at the time.

However, there were significant differences in the distribution of these computers. Students who attended schools with fewer minority students had significantly greater access to computers than did students in high-minority schools, with only 3 students to a computer in low-minority schools versus 4.1 students to a computer in high-minority schools.

On the other hand, while the availability of Internet computers is widespread in schools, the ways they are used appear to be quite different from the way students use them outside of school, and also different from the ways computers are used in the work world. While students outside of schools use computers and other Internet devices to interact with others, to create a web page or blog for others, and to share their own online creations, such as artwork, photos, stories, and videos, and while adults in the work world use ICT to collaborate and design new products, the use of computers by students in schools is quite pedestrian. According to a recent NCES (2010) national survey of teachers, the most common use of computers is for the learning or practicing of basic skills; 69% of teachers report that their students sometimes or often use computers for this purpose. This use is particularly prevalent in schools with a high percentage of students on free or reduced lunches; 85% of teachers in these schools report that their students use computers for this purpose, compared with 61% of teachers in schools with a small number of low-income students. Using computers to address real-world problems or collaborate on joint projects or products is minimal. Only 17% of teachers say their students often or sometimes use computers to develop or run simulations, demonstrations, or models. Only 13% say that, during their classes, their students use computers to design and produce a product, only 9% say they use it to contribute to a blog or wiki, and only 7% say they use it to connect with a social network site.

There are few national studies that ask students to report on the amount of time they spend using computers for educational purposes in and out of class. And there are few recent national studies that examine how computers are used in schools along with other pedagogical practices, such as conducting collaborative projects or scientific investigations; fewer still also look at student test performance related to these uses. The NETP recommends that more research be done in the area of ICT design and development, but it does not recommend large-scale research on technology-based classroom practice using nationally representative samples. This is a deficiency of both the educational technology research base and the recommendations of the NETP. More large-scale research studies of this sort are needed.

There is one national project – the National Assessment of Educational Progress (NAEP) – that collects data from both teachers and students on their backgrounds, classroom activities, and access to and uses of computers. Wenglinsky (2005) analyzed 2003 NAEP performance data in math, science, and reading, along with classroom pedagogical practices and computer use. He found that while the use of constructivist practices (such as project-based activities and the use of problems with multiple solutions) and constructivist computer activities (such as simulations and data analysis) had positive impacts on students' math and science scores on NAEP, the use of didactic pedagogical practices and drill and practice software had either no impact or a negative impact on student scores. Yet these practices tend to be used more often than constructivist practices, particularly with urban, poor, and minority students.

The Urgent Need for Educational Change

Of course, not all businesses or workers will be engaged in the information economy over the coming decades, any more than all businesses were related to farming in the agrarian economy or than all businesses were manufacturers during the mass-production economy. Nonetheless, the prevailing economic paradigm has a pervasive effect on all business and social endeavors. Economic historians (Freeman & Louca, 2001; Perez, 2002) describe waves of economic and social change associated with the introduction of transformative technologies. Each wave of technology – steam power, electrical power, mass production, and now computers – spawned both creative and disruptive forces that restructured the economy and rippled throughout social institutions and practices. The existing paradigm, tuned to a current set of technological affordances, was not able to cope with or take advantage of the potential offered by new technologies and, consequently, uptake of the new technologies was a disruptive force that worked against the current paradigm. As the new paradigm emerged, it spun off a whole host of corollary, mutually reinforcing businesses, social arrangements, and cultural practices. In this way, the new technologies came to be extremely creative forces as well. Over time, infrastructures, industries, organizational structures, and everyday practices realigned and became highly tuned to the affordances of the new technologies. These structures and practices also grew to be highly embedded in the economy and society and became a new 'common-sense' basis for organizing any activity and for structuring any institution, be it government, business, entertainment, or education. As organizations, practices, and people realign, the new paradigm fosters a quantum jump in productivity that modernizes and regenerates practically all economic activities. This can result in full employment, and the economic and social benefits of the new system become widespread.

The problem is that in America, we have an education system that is still highly tuned to the previous paradigm and that is misaligned with the needs of our changing economy and society. While people in the outside world work collaboratively and flexibly in distributed teams and use a variety of digital tools and resources to solve problems and create new ideas and products, students in schools meet in structured classrooms at specified times; teachers cover the standard content by lecturing in front of a large class while students listen; students work individually and reproduce this knowledge on assessments; and their use of ICT is limited. In keeping with the mass-production paradigm, ICT is most often used to increase the numbers taught, reduce costs, or increase performance on basic skills.

Darling-Hammond's (2010) view is more in keeping with the new paradigm: 'the new mission of schools is to prepare students to work at jobs that do not yet exist, creating ideas and solutions for products and problems that have not yet been identified, using technologies that have not yet been invented' (p. 2). The NETP positions the use of ICT in an education system transformed to meet the needs of this very different society and economy. It is part of a coordinated cluster of changes that encompass curriculum, pedagogical practices, assessment, teacher professional development, and school organization.

The NETP makes a number of infrastructure recommendations related to pervasive broadband access. Yet, with the exception of unequal distribution of resources, as noted by Warschauer & Martuchniak (2010), infrastructure is not the limiting factor. Evidence suggests that the infrastructure currently in place is under-utilized. The introduction of additional computers and networks will not, by itself, improve the future prospects of our students and our economy. The NETP identifies the other coordinated changes in curriculum, pedagogy, assessment, teacher professional development, and school structure that must take place to bring our education system into alignment with the needs of the twenty-first-century information economy and knowledge society. The evidence reviewed above supports these recommendations.

The NETP recommends that, beyond a core of standards-based concepts and competencies, the curriculum must be extended to include critical thinking, complex problem solving, and multimedia communications. Workplace technology is replacing the need not only for many manual skills but also for the routine cognitive skills that were the focus of the traditional curriculum and valued in the mass-production economic model. The recall of facts and the operation of simple procedures can now be performed much better by computers. These twenty-first-century skills are not only needed by employers, they are also needed to address the complex set of problems that are facing our society and our nation. A demanding curriculum that connects the fundamental concepts of the disciplines to complex, real-world problems and fosters the collaborative development of innovative, creative solutions will provide the high-level skills that our students need to compete internationally for high-value/high-pay jobs, and that our economy needs to sustain growth and maintain prosperity. Technology does not replace these skills but augments them. ICT competencies must be matrixed across the curriculum to enable students to use advanced technological tools and digital resources in designing the creative, innovative solutions to these problems.

The NETP recommends the use of technology to provide access to a much wider and more flexible set of learning resources than is available in traditional classrooms, and connections to a wider and more flexible set of educators, including teachers, parents, experts, and mentors outside the classroom. This breaks out of the teacher-led model that worked so well in the command-and-control, mass-production economy but that no longer works in the information economy. Technology can be used to connect students to a broad-based learning community, a set of authoritative experts and digital resources, and an assortment of knowledge-building tools that support and motivate their learning. Among these options is collaborative, project-based work built around challenges with real-world problems of personal relevance to the students. Such arrangements not only draw on and foster student engagement, they emulate the practices found in highly productive work settings.

The NETP recommends the use of ICT to provide students, teachers, parents, and school leaders with real-time information they can use to improve learning and teaching. Technologies such as simulations, games, multimedia scenarios, and virtual environments can be used to support assessment of complex concepts and high-level skills, such as collaboration, problem solving, critical thinking, and multimedia communication within the context of complex, real-world problems. These assessments go beyond the standardized measures of output that are so crucial to the mass-production economy, to include measures of a broader and more diverse range of outcomes, as well as the indicators of effective means of accomplishing them. ICT can be used to collect, analyze, and deliver these results quickly. The real-time delivery and analysis of these indicators can provide teachers and students with information they can use to improve their teaching and learning. And these assessments are more aligned with needs of an information-based economy.

The NETP recommends that we shift to a model of connected teaching, where ICT provides teachers with access to data, tools, resources, and communities of fellow educators, parents, and community organizers that can help them design, manage, and monitor learning environments and personalized plans that meet student needs. It also recommends the use of technology to provide teachers with career-long personal learning networks within and across schools, pre-service and in-service educational institutions, and professional organizations. This is the same way that businesses are using networks to support within- and across-organization collaboration.

Finally, the NETP recommends re-thinking the basic assumptions about school structure – when and where learning occurs, and the use of age-determined classes organized around disciplines. It recommends using technology to create more connections between elementary, high school, college, work, and home. The use of technology to penetrate the physical, temporal, and disciplinary boundaries of the classroom would bring school organization into alignment with the restructuring of business organizations that has accompanied ICT use.

In US businesses, ICT came to make an impact on productivity and innovation when it was implemented along with a cluster of other related practices and structural changes. So too in education, technology will make a difference if it is implemented along with a number of other coordinated changes. The NETP recommends a set of technology-based changes in curriculum, pedagogy, assessment, teacher professional development, and school structure that can transform education and that will prepare our students for life and work in the twenty-first century, and support economic and social progress. In this regard, the implementation of the NETP should be coordinated with other national, state, and local reform policies and efforts. Furthermore, policies within the education sector can have a greater impact on the economy if they are explicitly coordinated with the development of economic policy designed to support recovery and foster economic renewal (see, for example, Altman et al, 2010).

Education Secretary Arne Duncan acknowledges that the current state of education in the United States is 'economically unsustainable and morally unacceptable' (Office of Educational Technology, 2010, p. x). And President Obama declared that 'education is an economic issue – if not "the" economic issue of our time'. The NETP is an important step in connecting education reform to sustained economic growth and prosperity. And, in the words of the NETP, 'As we enter the second decade of the 21st century, there has never been a more pressing need to transform American education ...' (Office of Educational Technology, 2010, p. xii).

Notes

[1] http://www.bea.gov/industry/gdpbyind_data.htm

[2] Based on BEA figures, http://www.bea.gov/national/Index.htm

[3] http://www.bls.gov/emp/ep_table_201.htm

[4] Market capitalization, as of 23 July 2010. http://online.wsj.com/public/quotes/main.html

[5] Bureau of Labor Statistics, http://www.bls.gov/emp/ep_education_training.htm

[6] U.S. Census Bureau, http://www.census.gov/population/www/socdemo/education/cps2009.html

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