The Second Machine Age, Erik Brynjolfsson, Andrew Mcafee (2013)

Technology is a gift of God. After the gift of life, it is perhaps the greatest of God's gifts. It is the mother of civilizations, of arts and of sciences. (Freeman Dyson). Social development is a group's ability to master its physical and intellectual environment to get things done (Morris). It consists of 4 attributes: *energy capture* (per-person calories obtained from the environment for food, home, commerce, industry, agriculture, and transportation), *organization* (the size of the largest city), *war-making capacity* (number of troops, power and speed of weapons, logistical capabilities) and *information technology* (sophistication of tools for sharing and processing information).

Just over 200 years ago, something sudden and profound arrived and bent the curve of human history–of population and social development. The Industrial Revolution, which was the sum of several nearly simultaneous developments in mechanical engineering, chemistry, metallurgy, and other disciplines, underlie the sudden, sharp, and sustained jump in human progress. We can even be precise about which technology was most important. It was the steam engine developed and improved by James Watt and his colleagues in the second half of the 18th century.

Now comes the 2nd machine age. Computers and other digital advances are doing for mental power what the steam engine and its descendants did for muscle power. Mental power is at least as important for progress and development as physical power. Digital technologies had been laughably bad at a lot of these things for a long time—then they suddenly got very good. How did this happen and what are the implications of this progress which was astonishing and yet now considered a matter of course?

To answer these questions we spoke with inventors, investors, entrepreneurs, engineers, scientist, and many others who make technology and put it to work. The intellects at MIT make it a humbling place; the people make it a lovely one. We came to 3 broad conclusions. The 1st is that we're living in a time of astonishing progress with digital technologies—those that have computer hardware, software, and networks at their core. Just as it took generations to improve the steam engine to the point that it could power the Industrial Revolution, it's also taken time to refine our digital engines. We're at an inflection point—a point where the curve starts to bend a lot—because of computers.

The 2nd conclusion is that the transformations brought about by digital technology will be profoundly beneficial, bringing us more choices and freedom. They're subject to different economics, where abundance is the norm rather than scarcity. Digital goods are not like physical ones and these differences matter a lot.

The 3rd conclusion is less optimistic: digitization is going to bring with it some thorny challenges. Rapid and accelerating digitization is likely to bring economic disruption, stemming from the fact that as computers get more powerful, companies have less need for some kinds of workers. There's never been a worse time to be a worker with only 'ordinary' skills and abilities to offer, because computers, robots, and other digital technologies are acquiring these at an extraordinary rate. *Bounty* is the increase in volume, variety, and quality and the decrease in cost of the many offerings brought on by modern technological progress. *Spread* is the ever-bigger differences among people in economic success—in wealth, income, mobility, and other important measures.

Progress on some of the oldest and toughest challenges associated with computers, robots, and other digital gear was gradual for a long time. Then in the past few years it became sudden; digital gear started racing ahead, accomplishing tasks it had always been lousy at and displaying skills it was not supposed to acquire anytime soon. For example, robotics—building machines that can navigate through and interact with the physical world of factories, warehouses, battlefields, and offices--saw progress that was very gradual, then sudden.

Moravec's paradox: the discovery by artificial intelligence and robotics researchers that high-level reasoning requires very little computation, but low-level sensorimotor skills require enormous computational resources. The hard problems are easy and the easy problems are hard. It will be stock analysts, petrochemical engineers, and parole board members who are in danger of being replaced by machines.

The gardeners, receptionists, and cooks are secure in their jobs for decades to come. The volume and variety of robots in use at companies is expanding rapidly, and innovators and entrepreneurs have recently made deep inroads against Moravec's paradox. *SoLoMo*—social, local, and mobile—is the domain in which the smartphone has merged geological, meteorological, and medical together with media players, game platforms, reference works, cameras, and GPS devices together with tricorders (sensor scanning, data analysis, and data recorder) and person-to-person communicators.

Moore's Law (complexity for computer component costs increase at a rate of roughly 2x every 2 years) is very different from the laws of physics or Newtonian mechanics. It is a statement about the work of the computer industry's engineers and scientists; it's an observation about people and how constant and successful their efforts have been. This constant modification has made Moore's Law the central phenomenon of the computer age.

We are at a new inflection point. Self-driving cars; auto-generated news stories; cheap, flexible factory robots; and inexpensive consumer devices that are simultaneously communicators, tricorders, and computers have all appeared since 2006, as have countless other marvels that seem quite different from what came before. Sensors like microphones, cameras, and accelerometers have moved from the analog world to the digital one. They became, in essence, computer chips. As they did so, they became subject to the exponential improvement trajectories of Moore's Law. Steady exponential improvement has brought us into a new era when what's come before is no longer a reliable guide to what will happen next. Sometimes a difference in degree becomes a difference in kind. A notable exception to Moore's Law is batteries, which haven't improved at an exponential rate because they are chemical devices, not digital ones.

When you cannot express what you are speaking about in numbers, your knowledge is of a meagre and unsatisfactory kind (Lord Kelvin). The surge in digitization has had 2 profound consequences: new ways of acquiring knowledge (doing science) and higher rates of innovation. The unique economic property of digital information is that such information is non-rival and has zero marginal cost of reproduction. This means that digital information is not "used up" and is extremely cheap to copy. Rival goods, can only be consumed by one person at a time, i.e. food, housing, airline travel. Digitized music can be listened to without keeping anyone else from doing so at the same time or later. Making things free, perfect, and instant might seem like unreasonable expectations for most products, but as more information is digitized, more products will fall into these categories. Information is costly to produce but cheap to reproduce. One of the reasons that digitization is a main force shaping the 2nd machine age is that digitization increases understanding. It does this by making huge amounts of data readily accessible, and data are the lifeblood of science. By science we mean the work of formulating theories and hypotheses, then evaluating them; or guessing how something works, then checking to see if the guess is right. If you want to have good ideas you must have many ideas (Linus Pauling). Novelty has charms that our mind can hardly withstand (Makepeace Thackeray).

Innovation is the outstanding fact in the economic history of capitalist society and largely responsible for most of what we at first attribute to other factors (Joseph Schumpeter). There was almost no economic growth for the previous millennium prior to 1750 when the Industrial Revolution started. Human population growth and social development were very nearly flat until the steam engine came along. Once this growth got started it stayed on a sharp upward trajectory for 200 years. This was due not only to the original Industrial Revolution, but also to a 2nd one, it too reliant on technological innovation. Three novelties were central here: electricity, the internal combustion engine, and indoor plumbing with running water, all of which appeared between 1870 and 1900.

The growth of productivity (output per hour) slowed markedly after 1970. While puzzling at the time, it now seems clear that the one-time-only benefits of the Great Inventions and their spin-offs had occurred and could not happen again. All that remained after 1970 were second-round improvements, such as developing short-haul regional jets, extending the original interstate highway network with suburban ring roads, and converting residential America from window unit air conditioners to central air conditioning. (Bob Gordon).

There was a belief that we had been living off low-hanging fruit for at least 300 years, which during the last 40 years started disappearing. We were at a technological plateau (Tyler Cowen). Gordon and Cowen see the invention of powerful technologies as central to economic progress. The steam engine and electrical power quickly spread. The steam engine revolutionized land travel by enabling railroads and sea travel via the steamship. Electricity gave a further boost to manufacturing by enabling individually powered machines. It also lit factories, office buildings, and warehouses and led to further innovations like air conditioning, which made previously sweltering workplaces pleasant.

Economists call innovations like steam power and electricity general purpose technologies (GPTs). GPTs are important because they interrupt and accelerate the normal march of economic progress. The consensus of scholars recognizes that GPTs are pervasive, improve over time, and are able to spawn new innovations. Digital technologies meet all of these requirements and we believe that information and communication technology belong in the same category as steam and electricity as a GPT.

Of course data are the ultimate decider of hypotheses. The true work of innovation is not coming up with something big and new, but recombining things that already exist. To invent something is to find it in what previously exists (Brian Arthur). Meta-ideas are about how to support the production and transmission of other ideas (Paul Romer). Like language, printing, the library, or universal education, the global digital network fosters recombinant innovation. Digital innovation is recombinant innovation in its purest form. Digitization makes available massive bodies of data relevant to almost any situation, information which can be infinitely reproduced and reused because it is non-rival. As a result, the number of potentially valuable building blocks is exploding around the world, and the possibilities are multiplying as never before. We'll call this the 'innovation-as-building-block' view of the world. Unlike the 'innovation-as fruit' view, building blocks don't ever get eaten or otherwise used up. In fact, they increase the opportunities for future recombinations.

The constraint on the economy's growth then becomes its ability to comb through all these potential recombinations to find the truly valuable ones. In such a world the core of economic life appears increasingly to be centered on the intensive process of developing ever-greater numbers of new seed ideas into workable innovations. In the early stages of development, growth is constrained by the number of new ideas, but later on it is constrained only by the ability to process them. New growth is limited by our ability to process new ideas.

The outstanding features of the 2nd machine age are sustained exponential improvement in most aspects of computing, digitized information, and recombinant innovation. Machines that complete cognitive tasks are more important than those that accomplish physical ones. And thanks to modern AI (artificial intelligence) we now have them. We've also recently seen great progress in natural language processing, machine learning (the ability of a computer to automatically refine its methods and improve its results as it gets more data), computer vision, simultaneous localization and mapping, and many other fundamental challenges of the discipline. We're going to see AI do more and as this happens costs will go down, outcomes will improve, and our lives will get better.

Things have gotten better because there are more people who in total have more good ideas that improve our overall lot. In the long run, the most important economic effect of population size and growth is the contribution of additional people to our stock of useful knowledge. And this contribution is large enough in the long run to overcome all the costs of population growth.

Freedom of the press is limited to those who own one (A J Liebling). Billions of people will soon have a printing press, reference, library, school, and computer all at their fingertips. Most economic fallacies derive from the assumption that there is a fixed pie, that one party can gain only at the expense of another (Milton Friedman). The US GDP growth per person has averaged 1.9% per year since the early 1800s. Among individual firms in 1996 the heaviest IT users were dramatically more productive than their competitors. By the mid-1990s these benefits were big enough to become visible in the overall US economy, which experienced a general productivity surge.

In the late 1890s electricity was being introduced to American factories. but labor productivity growth didn't take off for over 20 years. While the technologies involved were very different, many of the underlying dynamics were quite similar. The slow start and subsequent acceleration of productivity growth in the electricity era matches the speed-up that began in the 1990s. GPTs always need complements. Coming up with those can take years, or even decades, and this creates lags between the introduction of a technology and the productivity benefits. We've seen this with both electrification and computerization. Perhaps the most important complementary innovations are the business process changes and organizational coinventions that new technologies make possible. As with earlier GPTs, significant organizational innovation is required to capture the full benefits of 2nd machine age technologies. Due in part to the power of digitization and networks to speed the diffusion of ideas, complementary innovations are happening faster than they did in the first machine age. Less than 10 years after its introduction, entrepreneurs were finding ways to use the Web to reinvent publishing and retailing.

While less visible, the large enterprise-wide IT systems that companies rolled out in the 1990s have had an even bigger impact on productivity. They did this mainly by making possible a wave of business process redesign. For example, Walmart drove remarkable efficiencies in retailing by introducing systems that shared point-of-sale data with their suppliers. The real key was the introduction of complementary process innovations like vendor managed inventory, cross-docking, and efficient consumer response that have become staple business-school case studies. They not only made it possible to increase sales from $1B/week in 1993 to $1B every 36 hours in 2001, but also helped drive dramatic increases in the entire retailing and distribution industries, accounting for much of the additional productivity growth nationwide during this period.

A large portion of the acceleration through 2000 can be traced to the sectors of the economy that produce or use IT equipment and software most intensively. Industries that were heavier users of IT tended to be more productive throughout the 1990s and 2000s while productivity fell slightly in those sectors that did not. The first 5 years of the 21st century saw a renewed wave of innovation and investment, this time less focused on computer hardware and more on a diversified set of applications and process innovations. It takes an average 5-7 years before the full productivity benefits of computers are visible in the productivity of the firms making the investments. For every dollar of investment in computer hardware, companies need to invest up to another 9 dollars in software, training, and business process redesign. Like earlier GPTs, the power of computers was their ability to affect productivity far from their 'home' industry. The productivity lull after the introduction of electricity did not mean the end of growth, nor did the lull in the 1970s. Part of the recent slowdown simply reflects the Great Recession and its aftermath. Recessions are always times of pessimism and that invariably spills over into predictions about technology and the future.

The Gross National Product does not include the beauty of our poetry or the intelligence of our public debate. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion. It measures everything, in short, except that which makes life worthwhile. (Robert Kennedy). The great irony of this information age is that we actually know less about sources of value in the economy than we did 50 years ago. In fact, much of the change has been invisible simply because we did not know what to look for. There's a huge layer of the economy unseen in the official data and unaccounted for on the income statements and balance sheets of most companies. Free digital goods, the sharing economy, and intangible changes in our relationships have already had big effects on our well-being. Music is hiding itself from our traditional economic statistics. Sales of music on physical media declined from 800M units in 2004 to less than 400M units in 2008. Yet over the same period total units of music purchased still grew, reflecting an even faster increase in the purchases of digital downloads. Music disappeared as measured by price, not value. From 2004 to 2008, the combined revenue from sales of music declined by 40% from $12.3B to $7.4B.

Similar economics apply when you read the *New York Times, Bloomberg Businessweek,* or *MIT Sloan Management Review* online at a reduced price or for free instead of buying a physical copy at the newsstand, or when you use Craigslist instead of the classified ads, or when you share photos via Facebook instead of mailing prints around to friends and relatives. Analog dollars are becoming digital pennies. A copy of a digital good is identical to the original. This leads to some very different economics and measurement problems. How do we measure the benefits of free goods or services that were unavailable at any price in previous eras? GDP, even if it were perfectly measured, does not quantify our welfare. Children with smartphones today have access to more information in real time via the mobile web than the president of the US did 20 years ago. Because they have zero price, these services are invisible in the official statistics. They add value to the economy, but not dollars to GDP. When a girl clicks on a YouTube video instead of going to the movies, she's saying that she gets more net value from YouTube than traditional cinema. When her brother downloads a free gaming app on his iPad instead of buying a new video game, he's making a similar statement. The proliferation of free products pushes GDP downward. If the cost of creating and delivering an encyclopedia to your desktop is a few pennies instead of thousands of dollars, then you're certainly better off. But this decrease in cost *lowers* GDP even as our personal well-being increases, pushing GDP in the opposite direction of our true well-being. With a greater volume of digital goods introduced each year that do not have a dollar price, this traditional GDP heuristic is becoming less useful.

The information sector's contribution to the economy is the sum of the sales of software, publishing motion pictures, sound recording, broadcasting, telecommunications, and information and data processing services. According to the official measures, these account for just 4% of our GPD today, almost the same share as in the late 1980s before the World Wide Web was even invented. But clearly this isn't right. The official statistics are missing a growing share of the real value created in our economy. Americans nearly doubled the amount of leisure time they spent on the Internet between 2000 and 2011. By considering the value of users' time and comparing leisure time spent on the Internet to time spent in other ways, it is estimated that the Internet created about $2600 of value per user each year, none of which showed up in GDP. Last year users collectively spent about 200m hours each day just on Facebook, much of it creating content for other users to consume. That's 10X as many people-hours as were needed to build the entire Panama Canal, and none of this is counted in our GPD. The official GDP misses the value of new goods and services added to the tune of about 0.4% of additional growth each year.

Increased transparency has helped smaller independent restaurants compete with bigger chains because customers can more quickly find quality food via rating services like Yelp, reducing their reliance on brand names' expensive marketing campaigns. Production in the 2nd machine age depends less on physical equipment and structures and more on 4 categories of intangible assets: intellectual property, organizational capital, user-generated content, and human capital.

The 2nd—and even larger—category of intangibles is organizational capital like new business processes, techniques of production, organizational forms, and business models. When companies spend millions of dollars on computer hardware and software for a new enterprise resource planning system, they typically also include process changes that are 3-5X as costly as the original investments in hardware and software. The new business processes, which often outlast the hardware, are generally not counted as capital. A correct accounting for computer-related intangible assets would add over $2t to the official estimates of the capital assets in the US economy. The value of human capital in the US is 5-10X larger than the value of physical capital. Important as these intangible assets are, the official GDP ignores them. User-generated content, for example, involves unmeasured labor creating an unmeasured asset that is consumed in unmeasured ways to create unmeasured consumer surplus. Estimates of investment in R&D capital accounted for about 2.9% of GDP and has increased economic growth by about 0.2% per year between 1995 and 2004.

It's a fundamental principle of management that what gets measured gets done. Although GDP is among the great inventions of the 20th century, the rise in digital business innovation means that we need innovation in our economic metrics. If we measure only tangibles, then we won't catch intangibles that will make us better off. If we don't measure pollution and innovation, then we will get too much pollution and not enough innovation. Not everything that counts can be counted, and not everything that can be counted, counts. The gap between what we measure and what we value grows every time we gain access to a new good or service that never existed before or becomes free.

For almost 200 years wages increased alongside productivity. This created a sense of inevitability that technology helped (almost) everyone. But more recently median wages have stopped tracking productivity, underscoring the fact that such a decoupling is not only a theoretical possibility but also an empirical fact in our current economy. The year 1999 was the peak year for the real (inflation-adjusted) income of the median American household. It reached $54,932 that year, but then started falling. By 2011, it had fallen nearly 10% to $50,054, even as overall GDP hit a record high. In particular, wages of unskilled workers in the US and other advanced countries have trended downward. For the first time since before the Great Depression, over half the total income in the US went to the top 10% of Americans in 2012. The top 1% earned over 22% of income, more than doubling their share since the early 1980s. While overall life expectancy continues to rise, life expectancies for some groups have started to fall. The average life expectancy of a white woman without a high school diploma fell from 78.5 years in 1990 to 73.5 years in 2008, while it fell by only 3 years for white men without a high school diploma during this period.

Between 1983 and 2009 Americans became vastly wealthier overall as the total value as their assets increased. However, the bottom 80% of the income distribution saw a net decrease in their wealth. The top 20% gains included not only the newly created wealth in the economy but also wealth that shifted in their direction from the bottom 80%. The trend of falling median income is similar worldwide across institutions, government policies, and cultures.

The new coinvention of organization and technology not only significantly increased productivity but tended to require more educated workers and reduce demand for less-skilled workers. Companies with the biggest IT investments typically made the biggest organizational changes, usually with a lag of 5-7 years before seeing the full performance benefits. Work can be divided into a 2 by 2 matrix: cognitive versus manual and routine versus nonroutine. The demand for work has been falling most dramatically for routine tasks, regardless of whether cognitive or manual. This leads to job polarization: a collapse in demand for middle-income jobs, while nonroutine cognitive jobs (such as financial analysis) and nonroutine manual jobs (like hairdressing) have held up relatively well. Advances in IT have rendered many routine information-processing jobs superfluous. At the same time, when profits and revenues are on the rise, it can be hard to eliminate jobs. When the Great Recession came, business as usual was not sustainable, which made it easier to implement a round of painful streamlining and layoffs. As the recession ended and profits and demand returned, jobs doing routine work were not restored. Organizations found they could use technology to scale up without workers.

In the past decade, the relatively consistent division between the shares of income going to labor and physical capital seems to be coming to an end. In the US the share of GDP going to labor which averaged 64% from 1947 to 2000 declined to 58% in 2010. Fewer people are working and wages for those who are working are lower than before. As productivity is growing the owners of physical capital are capturing the increased value to a large extent.

One machine can do the work of 50 ordinary men, but no machine can do the work of one extraordinary man (Elbert Hubbard). The ratio of CEO pay to average worker pay increased from 70 in 1990 to 300 in 2005. Each time a market becomes more digital, the winner-take-all economics become more compelling. In winner-take-all markets compensation is mainly determined by *relative* performance, whereas in traditional markets revenues more closely tracked *absolute* performance. To understand the distinction, suppose the best brick layer could lay 1000 bricks in a day while the 10th best laid 900. In a traditional market, someone who is 90% as skilled or efficient earns 90% as much money. That's absolute performance. By contrast, a software programmer who writes a slightly better mapping application—one that loads a little faster, has slightly more complete data, or better icons—might completely dominate a market. Quantity can't make up for quality.

With digital goods capacity constraints become increasingly irrelevant. The economics of personal services (nursing) or physical work (gardening) are very different, since each provider, no matter how skilled or hard-working can only fulfill a tiny fraction of the overall market demand. When an activity transitions from the 2nd category to the 1st the way tax preparation did, the economic shifts toward winner-take-all outcomes and creative destruction, where each innovation not only creates value for consumers but also wipes out the previous incumbent. They are also 'scale invariant,' which means that the top-selling book accounts for about the same share as the top ten books do for the top 100, or as the top 100 do for the top 1000. These power laws describe many phenomena, from frequency of earthquakes to the frequency of words in most languages. They also describe the sales distribution of books, DVDs, apps, and other information products.

The US economy as a whole can be described as a mixture of a log-normal distribution (a variant of the classical normal distribution) and power law, with the power law fitting the incomes at the top best. The era of bell curve distributions that supported a bulging social middle class is over and we are headed for a power-law distribution of economic opportunities. The mean of a power-law distribution is much higher than the median. For instance, in 2009, the mean salary for major league baseball players was $3,240,000, roughly 3X the median salary of $1,150,000.

Productivity and employment have become decoupled. When combined with political and economic systems that offer people choices, technological advance is an awe-inspiring engine of betterment and bounty. It is also an engine driving spread, creating growing differences in wealth, income, standards of living, and opportunities for advancement. Future technologies will tend to increase spread, just as they will boost bounty. Everyone benefits, though not all benefit the same. Spending by households on many basics--food at home, automobiles, clothing, furniture, housing, and utilities—fell from 53% of disposable income in 1950 to 44% in 1970 to 32% in 2012.

Between 1990 and 2008 family incomes grew about 20%, prices for housing and college by 50%, and health care by more than 150%. Nearly half of Americans cannot come up with $2000 in 30 days--meaning that they judge themselves to be financially fragile--including many seemingly middle class.

While economic bounty from technology is real, it is not sufficient to compensate for huge increases in spread. Stagnant and falling incomes now combine with decreasing social mobility, an ever lower chance that children born at the bottom end of the spread will escape their circumstances and move upward throughout their lives and careers. Economic conditions and prospects have worsened in recent decades for the children of parents with only high school educations even as they've improved for college-educated families. The origins of power, prosperity and poverty are not geography, natural resources, or culture. Instead they're institutions like democracy, property rights, and the rule of law; inclusive ones bring prosperity, and extractive ones—ones that bend the economy and the rules of the game to the service of the entrenched elite—bring poverty.

Prosperity depends on innovation, and we waste innovative potential if we do not provide a level playing field for all: we don't know where the next Microsoft, Google, or Facebook will come from, and if the person who will make this happen goes to a failing school and cannot get into a good university, the chances that it will become a reality are diminished. Economic inequality will lead to greater political inequality, and those who are further empowered politically will use this to gain greater economic advantage, stacking the cards in their favor and increasing economic inequality still further in a vicious circle.

Faster technological progress may ultimately bring greater wealth and longer lifespans, but it also requires faster adjustment by both people and institutions. In the long run we may not be dead, but we still need jobs. People need to work for their own sense of self-worth, if for nothing else, but there is a floor on how low wages for human labor can go. In turn, that floor can lead to unemployment for people who want to work, but are unable to find jobs. If neither the worker nor any entrepreneur can think of a profitable task that requires that worker's skills and capabilities, then that worker will go unemployed indefinitely. Over history, this has happened to many other inputs to production that were once valuable, from whale oil to horse labor. The data show that employment grew alongside productivity up until the end of the 20th century, but in the last 15 years job growth decoupled from productivity. Which history should we take guidance from: the 2 centuries ending in the late 1990s, or the 15 years since then?

Once an industry become largely automated, the case for locating a factory in a low-wage country becomes less compelling. There may still be logistical advantages if the local business ecosystem is strong, making it easier to get spare parts, supplies, and custom components. But over time inertia may be overcome by the advantages of reducing transit times for finished products and being closer to customers, engineers and designers, educated workers, or regions where the rule of law is strong.

Interactive voice-response systems are automating jobs in call centers. United Airlines has been successful in making such a transition. This can disproportionally affect low-cost workers in places like India and the Philippines. Similarly, many medical doctors used to have their dictation sent overseas to be transcribed. But an increasing number are now happy with computer transcription. Offshoring is often only a way station on the road to automation. In the long run, low wages will be no match for Moore's Law. Trying to fend off advances in technology by cutting wages is only a temporary protection.

Ideation in its many forms is an area today where humans have a comparative advantage over machines. Judge a man by his questions, not his answers (Voltaire). A partnership between Dr. Watson (an IBM computer) and a human doctor will be far more creative and robust than either of them working alone. Ideation, large-frame pattern recognition, and the most complex forms of communication are cognitive areas where people still have the advantage and seem likely to hold on to it for some time to come.

The Italian physician and researcher Maria Montessori developed the primary educational system that still bears her name. Montessori classrooms emphasize self-directed learning, hands-on engagement with a wide variety of materials, and a largely unstructured school day. And in recent years they've produced alumni including the founders of Google (Larry Page and Sergey Brin), Amazon (Jeff Bezos), and Wikipedia (Jimmy Wales). These examples appear to be part of a broader trend. Researchers have found that a disproportionate number of them also went to Montessori schools, where they learned to follow their curiosity. The Montessori educational approach might be the surest route to joining the creative elite, which are so overrepresented by the school's alumni that one might suspect a Montessori Mafia. People can remain valuable knowledge workers in the new machine age by working to improve the skills of ideation, large-frame pattern recognition, and complex communication instead of just the 3 Rs. Whenever possible, take advantage of self-organizing learning environments, which have a track record of developing these skills in people.

College students today spend only 9% of their time studying (compared to 51% socializing, recreating, and other activities), much less than in previous decades. Only 42% have taken a class the previous semester that required them to read at least 40 pages a week and write at least 20 pages total. Higher education is emerging as an institution focused more on social than academic experiences. Students spend very little time studying, and professors rarely demand much from them in terms of reading and writing. Those students who spent more time studying (especially studying alone), took courses with more required reading and writing, and had more demanding faculty improved the most in the Collegiate Learning Assessment. The impact of college is largely determined by individual effort and involvement in the academic, interpersonal, and extracurricular offerings on a campus. Study hard, using technology and all other available resources to 'fill up your toolkit' and acquire skills and abilities that will be needed in the 2nd machine age. One of the best known of these resources is Khan Academy (www.khanacademy.org).

College graduates are the only group that has seen employment growth since the start of the Great Recession in 2008. The college premium exists in part because so many types of raw data are getting dramatically cheaper and the bottleneck increasingly is the ability to interpret and use data. Seek to be an indispensable complement to something that's getting cheap and plentiful. Inequality is a race between education and technology. When technology advances too quickly for education to keep up, inequality generally rises. The most educated places in the country, like Austin, Texas, Boston; Minneapolis, and San Francisco, have low unemployment rates. The good news is that compared to other industries such as media, retailing, finance, or manufacturing, education is a tremendous laggard in the use of technology. That's good news because it means we can expect big gains simply by catching up to other industries. Digital education creates an enormous stream of data that makes it possible to give feedback to both teacher and student. Educators can run controlled experiments on teaching methods and adopt a culture of continuous improvement. The real impact of MOOCs (massive online open courses) is mostly ahead of us in scaling up the reach of the best teachers, devising methods to increase the overall level of instruction, and in measuring and finding ways to accelerate student improvement. Improvements in the grading of essays are important because essays are better at capturing student learning than multiple-choice questions, but much more expensive to grade when human graders are used. Automatic grading of essays would both improve the quality of education and lower its cost.

One consistent finding from educational research is that teachers matter. In fact, the impact of a good teacher can be huge. Students assigned to better teachers (as measured by their impact on previous students' test scores) earned more as adults, were more likely to attend college, and were less likely to have children as teenagers. They also found that the differences between poor and average teachers can be as important as the ones between average and superior teachers. Replacing a bottom 5% teacher with an average teacher would increase the present value of students' lifetime income by more than $250,000 for the average classroom.

Studies of successful charter schools have found that the formula for success is simple, if not easy: longer hours, additional school days, and a no-excuses philosophy that test students and, implicitly, their teachers. Rich and poor children learn at a similar rate when school is in session, but poor children fall behind over the summer when they are not in school. Hard-to-measure skills like creativity and unstructured problem solving are increasingly important as machines handle more routine work. Strong incentives for achieving measurable goals can crowd out hard-to-measure goals.

Reducing the supply of unskilled workers will relieve some of the downward pressure on their wages, while increasing the supply of educated workers diminishes the shortages in those areas. Innovation is the market introduction of a technical or organizational novelty, not just its invention. Net job creation is much higher at young companies even through wages are lower. Any single regulation might not do much to deter new business formation, but each one is like another pebble blocking a stream. Their cumulative effect can be increasingly damaging as opportunities to work around them are diminished.

Economics teaches that basic research has large beneficial externalities. This fact creates a role for government, and the payoff can be enormous. The Internet, GPS systems, touchscreen displays, voice recognition software, and many other digital innovations arose from basic research sponsored by the government. Over the past decade, the total federal and private funds earmarked for large prizes have more than tripled and now surpass $376M. But it's just a tiny fraction of overall government spending on research. There remains great scope for increasing the volume and variety of innovation competitions. A series of prizes totaling over £100,000 motivated major advances throughout the 1700s in the measurement of longitude. In 1919, the $25,000 Orteig Prize for a nonstop transatlantic flight motivated a series of aviation innovations, culminating in Charles Lindbergh's successful flight in 1927. Like education and research, infrastructure is subject to positive externalities. Excellent infrastructure makes a country a more pleasant place to live and a more productive place in which to do business. Bringing US infrastructure up to an acceptable grade would be one of the best investments the country could make in its own future.

Generous immigration policies are part of the Econ 101 playbook; there is wide agreement among economists that they benefit not only the immigrants themselves but also the economy of the country they move to. Since 2007, it appears that net illegal immigration to the US is zero or negative. Between 1990 and 2005, 25% of America's highest-growth companies were founded by foreign-born entrepreneurs. Increasing the number of immigrant engineers actually leads to higher wages for native-born engineers because immigrants help creative ecosystems flourish. Today immigrants are having a large and beneficial effect on the country not because of America's process and policies, but often despite them. Immigration to the US is often slow, complex, inefficient, and highly bureaucratic, a 19th century process in a 21st century world. In addition to a broken process the US also has counterproductive policies, particularly for technologists with their annual cap of H1-B visas.

Congestion-reducing activities like carpooling, off-peak commuting, bicycling, telecommuting, and mass transit would all increase with congestion pricing in effect. The revenues from optimal congestion pricing would be enough to eliminate all state taxes in California. In the past, it was impossible to meter road usage in a cost-effective way, so we settled for leaving it unpriced and putting up with what resulted--the kinds of long lines and waiting we rarely saw outside of the former Soviet Union for goods and services. Digital road pricing systems could help us recapture that lost time while replacing revenues from other sources.

Work saves a man from 3 great evils: boredom, vice, and need (Voltaire). As digital labor become more pervasive, capable, and powerful, companies will be increasingly unwilling to pay people wages that they'll accept and that will allow them to maintain the standard of living to which they've been accustomed. When this happens, they remain unemployed. This is bad news for the economy, since unemployed people don't create much demand for goods and overall growth slows down. Weak demand can lead to further deterioration in wages and unemployment as well as less investment in human capital and equipment, and a vicious cycle can take hold.

A number of economists have been concerned about this possible failure mode of capitalism. Many of them have proposed the same simple solution; give people money. The easiest way to do this would have the government distribute an equal amount of money to everyone in the country each year, without doing any means of testing or other evaluation of who needs the money or who should get more or less. This 'basic income' scheme is comparatively straightforward to administer and preserves the elements of capitalism that work well while addressing the problem that some people can't make a living by offering their labor. However, it's tremendously important for people to work, not just because that's how they get their money, but also because it's one of the principal ways they get many other important things: self-worth, community, engagement, healthy values, structure, and dignity, to name just a few. Work is beneficial at the individual level and makes people feel fulfilled, content, and happy, deriving from 3 key motivations: mastery, autonomy, and purpose.

The primary wish of the world is no longer peace or freedom or even democracy. It is first and foremost to have a good job. Everything else comes after that. The consequences of high neighborhood joblessness are more devastating than those of high neighborhood poverty. A neighborhood in which people are poor but employed is different from a neighborhood in which many people are poor and jobless. Many of today's problems in urban ghetto neighborhoods—crime, family dissolution, welfare, low levels of social organization, and so on—are fundamentally a consequence of the disappearance of work. Communities in which people are working are much healthier than communities where work is scarce, all other things being equal. States with more generous EITC (earned income tax credit) policies have significantly greater intergenerational mobility. The EITC is really a subsidy on labor.

In 2010 approximately 30% of the American workforce lived in Belmont (a symbolic community of those with at least a college education and a professional or managerial job) and 20% lived in Fishtown (a community of those with no more than a high school education and a blue-collar or clerical job). In 1960 90% of Belmont households had at least one adult working 40 or more hours a weeks, as did 81% of Fishtown households. By 2010 the situation had changed drastically. While 87% of Belmont household still had at least one person working that much, only 53% of Fishtown households did.

The amount of data that's being digitized is growing even faster than Moore's Law. The sheer density and complexity of our digital world brings risk with it. Any system this complex and tightly coupled has 2 related weaknesses. First, it's subject to seeing minor initial flaws cascade via an unpredictable sequence into something much larger and more damaging. Such a cascade characterized the 1979 meltdown of the 3 Mile Island nuclear plant, the August 2003 electrical blackout that affected 45M people throughout the US Northeast, and many other incidents. Second, complex tightly coupled systems make tempting targets for spies, criminals, and those who seek to wreak havoc. The same scientific breakthroughs in genome sequencing that can be used to cure disease can also be used to create a weaponized version of the smallpox virus. Computer programs can also self-replicate, becoming digital viruses, so the same global network that spreads ideas and innovations can also spread destruction.

To paraphrase Martin Luther King, Jr., the arc of history is long but it bends towards justice. We think the data support this. We've seen not just vast increases in wealth but also more freedom and social justice, less violence, and less harsh conditions for the least fortunate with greater opportunities for more and more people. In the long run, the real questions will go beyond economic growth. As more and more work is done by machines, people can spend more time on other activities. Not just leisure and amusements, but also the deeper satisfactions that come from invention and exploration, from creativity and building, and from love, friendship, and community. As we have fewer constraints on what we can do, it is then inevitable that our values will matter more than ever.

[*SoLoMo*—social, local, and mobile—is the domain in which the smartphone has merged geological, meteorological, and medical together with media players, game platforms, reference works, cameras, and GPS devices together with tricorders (sensor scanning, data analysis, and data recorder) and person-to-person communicators. The constant modification of how people work has made Moore's Law the central phenomenon of the computer age. Sensors became, in essence, computer chips. As they did so, they became subject to the exponential improvement trajectories of Moore's Law. The surge in digitization has had 2 profound consequences: new ways of acquiring knowledge (doing science) and higher rates of innovation. The unique economic property of digital information: non-rival with zero marginal cost of reproduction. Making things free, perfect, and instant might seem like unreasonable expectations for most products, but as more information is digitized, more products fall into these categories. Innovation is the outstanding fact in the economic history of capitalist society. Meta-ideas are about how to support the production and transmission of other ideas. Like language, printing, the library, or universal education, the global digital network fosters recombinant innovation. Digital innovation is recombinant innovation in its purest form. New growth is limited by our ability to process new ideas. The outstanding features of the 2nd machine age are sustained exponential improvement in most aspects of computing, digitized information, and recombinant innovation. In the long run, the most important economic effect of population size and growth is the contribution of additional people to our stock of useful knowledge. The US GDP growth per person has averaged 1.9% per year since the early 1800s. The heaviest IT users were dramatically more productive than their competitors. The decrease in information cost *lowers* GDP even as our personal well-being increases, pushing GDP in the opposite direction of our true well-being. Work can be divided into a 2 by 2 matrix: cognitive versus manual and routine versus nonroutine. The demand for work has been falling most dramatically for routine tasks. Nonroutine cognitive jobs (such as financial analysis) and nonroutine manual jobs (like hairdressing) have held up relatively. The US is a mixture of a log-normal distribution (a variant of the classical normal distribution) and power law, with the power law fitting the incomes at the top best. The era of bell curve distributions that supported a bulging social middle class is over and we are headed for a power-law distribution of economic opportunities. Judge a man by his questions, not his answers. The Montessori educational approach might be the surest route to joining the creative elite, which are so overrepresented by the school's alumni that one might suspect a Montessori Mafia. Work saves a man from 3 great evils: boredom, vice, and need. The primary wish of the world is no longer peace or freedom or even democracy. It is first and foremost to have a good job. The consequences of high neighborhood joblessness are more devastating than those of high neighborhood poverty.]