CHAPTER 18

Technology and Humanity for Industry 4.0 and Learning 4.0

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Scientific discoveries and engineering innovation are accelerating the unprecedented convergence of the physical, digital and biological worlds to produce technological advances that are poised to disrupt and transform the daily lives of ordinary citizens at an ever-increasing pace [1, 2]. This ongoing transformation has been broadly and commonly referred to as the Fourth Industrial Revolution or Industry 4.0 [3].

The disruptions engendered by this revolution have been catalysed by developments in many research and applied fields. They include, but are not limited to:

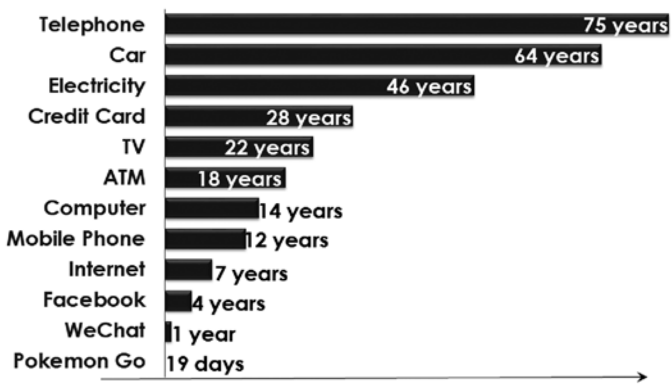
1. computing hardware and software;
2. massive and deep data analytics;
3. blockchain;
4. mobile communication technologies, augmented in the future by 5G;
5. autonomy and intelligence of machines and robots;
6. advanced additive manufacturing;
7. personalized medicine;
8. augmented and virtual reality;
9. industrial internet of things;
10. genomics, gene-editing and computer chips augmented with genome-analysing features;
11. nanotechnology; and
12. metrology enabling improvements in precision and resolution with which time, location, as well as physical and chemical properties and characteristics of matter and objects, can be measured.

TECHNOLOGY AND INDUSTRY 4.0

The First Industrial Revolution, originating in Scotland in the 18th century, was propelled by the mechanization of labour by recourse to steam and water as energy sources which replaced human and animal labour. The Second Industrial Revolution, also commonly known as the Technological Revolution, which evolved from the late the 19th Century until World War I, was marked by advances in electrification, factory assembly lines, machining, rail transportation, metal processing, manufacturing and telegraphic communication. Industry 3.0 was catalysed in the 20th century by advances in microprocessors and computing, automation, robotics, programmable logic controllers and the evolution of global supply chains.

By comparison to the previous three industrial revolutions, Industry 4.0 is marked by a number of unique characteristics:

Figure 1– The time required for different technologies to mature and to be adopted by the first 50 million users. Data courtesy of *The Wall Street Journal* and Valuecapitalist.com.



Source: Time to reach the first 50 million users

1. The pace of technological change and disruption has never been faster and the ensuing implications for individuals and societies have never been more pronounced. Figure 1 is an illustration of the accelerating pace of innovation and its widespread adoption of technologies around the globe. Their transformative effects impact the lives and livelihoods of billions of global citizens.
2. Aspects of normal and routine human endeavour will be increasingly influenced by decisions made by machines with real-time access to massive amounts of aggregated data. Such decisions are expected to have a profound impact on the daily lives of humans in areas as

diverse as transportation, medical diagnosis and treatment, managing personal well-being, manufacturing, logistics and supply chain, assisted living, cradle-to-grave education and learning, delivery of healthcare, and care of the elderly, those with special needs, and children. Industry 4.0 has accelerated bi-directional communication between the individual citizen of the world and the leading edge of disruptive transformation by recourse to mobile technologies. This trend is poised to see a major leap in coming years as 5G communication technologies will be rolled out in the not-too-distant future.

3. Personalized machine learning algorithms, incorporating either unsupervised or partially supervised learning, are also used to target individuals, organizations and communities to automatically flood them with information/misinformation at speeds much faster than properly vetted, reviewed and authenticated real news can travel. These technology-enabled communication channels employing websites and social media often intentionally obfuscate the unsuspecting target by trumping truthful information with sophisticated and seemingly authentic fake news or information predicated on biased data and statistics. They can also instigate political, financial, commercial and even physical harm to citizens, communities and countries.
4. Industry 4.0, unlike at any previous juncture in human history, raises fundamental questions about the potential for humanity to be altered by technology. It also raises concerns about the degree of long-term irreversibility associated with the influence of technology in such areas of societal importance as climate change, sustainability of the planet and of the quality of life of its inhabitants, equality of income and opportunities, fairness, ethics, risk, liability, regulations, responsibility and governance.

INDUSTRY 4.0 AND HUMANITY 4.0

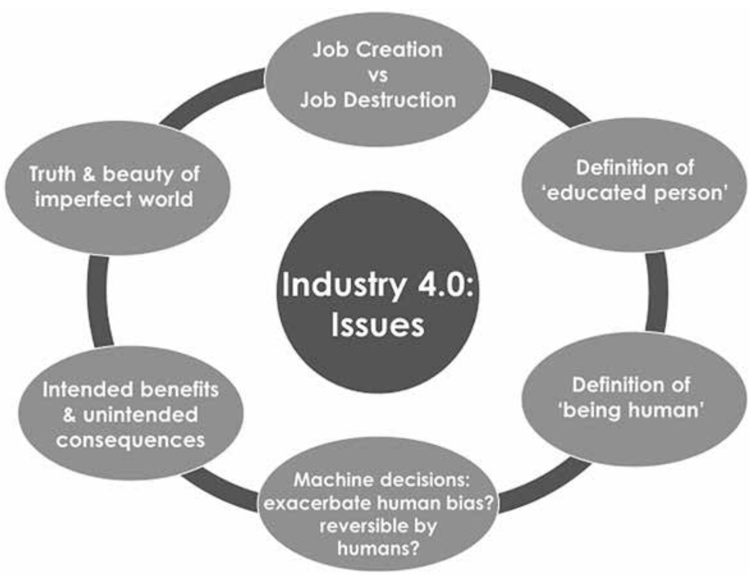
The foregoing unique characteristics of Industry 4.0 raise many fundamental issues and challenges for humanity. Here we pose six major questions. How societies address these issues individually and collectively will determine whether technological advances influencing the fourth industrial revolution will ultimately turn out to be net positive or net negative for humanity.

1. Every previous industrial revolution resulted in massive job losses, but it ultimately (and, in most cases, over a span of several decades) led to the creation of more jobs than the number of jobs eliminated. In Industry 4.0, with an unprecedented pace of anticipated rapid societal change, a long time delay between the elimination of

current jobs through the wider adoption of "intelligent" machines and the creation of new jobs is expected to further accentuate the growing disparities in income and in quality of life among citizens of many countries. This could also lead to further polarization of countries and societies toward extremes.

2. A high school or university graduate today is expected to continually learn to adapt to the transformative changes created by technology. Today's graduate is also expected to change jobs and even professions many times over the course of a long career. In order to succeed in the increasingly competitive global marketplace driven by greater efficiency, what is the "minimum body of knowledge" a university graduate is supposed to acquire during formal education so as to be prepared to acquire new skills over a lifetime of rapid changes in workforce needs? What are the roles and responsibilities of educators, employers and governments in providing these basic skills not only during the early years of formal learning and employment, but also for continual "re-skilling" and "upskilling" for "lifelong learning" throughout one's career and life? What does it mean to be "an educated person" in the 21st century?

Figure 2– Six of the key issues and questions surrounding Industry 4.0 as human behaviour interfaces with technological advances and with disruptions arising from such advances.



3. As noted earlier, technologies enabled by advances in such fields as computing, artificial intelligence, machine learning, and real-time and deep data analytics are poised to play an important role in determining, influencing and controlling a vast spectrum of human endeavours and activities. At the same time, distinct differences arising from cultural, social, national and family circumstances, along with individual life experiences, uniquely shape the evolution of non-duplicative characteristics of each human being. Manifestations of individual uniqueness among billions of people lead to such distinctly human characteristics influenced by personal values such as dignity, ethics, empathy, compassion, sympathy, pride and honour. With decisions made through the agglomeration of massive amounts of data, will machine decisions begin to influence human activities in a manner that distorts innate individual characteristics and values and the ensuing behaviour patterns? Whose algorithms and perspectives will determine values that are important to an individual, on what basis, and relying on what kinds of data? Who will authenticate and vouch for the veracity of such data? In other words, in the era of Industry 4.0 in which human actions and activities are expected to be increasingly influenced by machine intelligence and decisions, what will it mean "to be human"?
4. There is existing evidence that biased data input or algorithms for neural networks and machine learning, involving such technologies as face recognition, can sometimes lead to bad, unacceptable, and even "evil" decisions. Will machines help mitigate or exacerbate innate human biases, whether conscious or unconscious, through bad, erroneous, unreliable or insufficient data? Under what conditions can machine decisions become irreversible and permanent making human intervention impossible, irrelevant or immaterial?
5. Many technological advances ultimately lead to the betterment of human condition. Most of them also create unintended consequences that have deleterious effects on humans and society. In 2000, at the dawn of the new century and the new millennium, the National Academy of Engineering (NAE) of the United States released a list of 20 greatest engineering achievements of the 20th century (see: http://www.greatachievements.org/). This list includes impressive accomplishments such as: electrification, automobile, airplane, computers, internet and nuclear technologies. Several years later, NAE also released a report on the 14 grand challenges of the 21st century (see: http://www.engineeringchallenges.org/). This latter report includes such global challenges as: restoring and improving urban infrastructure, securing cyberspace, providing access to clean water,

preventing nuclear terror, and developing carbon sequestration methods. When we examine the two lists side by side, we cannot help but wonder whether some of the greatest engineering achievements of the 20th century played a pivotal role in creating some of the toughest grand challenges for the 21st century. The greatest engineering achievements of the last century led to enormous benefits to humankind and elevated quality of life around the globe. At the same time, in the course of solving some of the hardest technological problems to produce innovative products that led to many tangible benefits to society, we created some of the most difficult challenges and unintended consequences for succeeding generations. Then, how likely is it that our even greater technological accomplishments of the 21st century driving Industry 4.0 will not lead to even grander challenges for the 22nd century? What was missing in our collective thinking in the last century that needs to be addressed now so that we do not repeat our past mistakes in this century?

6. Technology has advanced to a level of sophistication whereby Global Positioning System (GPS) can pinpoint a location with real-time kinematic positioning to centimetre-level resolution (https://en.wikipedia.org/wiki/Real-time_kinematic). Atomic clocks routinely monitor time to a level of temporal accuracy whose error rate is better than a billionth of a second per day (https://en.wikipedia.org/wiki/Atomic_clock). Transmission electron microscopes now routinely provide clear images of individual atoms in materials with spatial resolution on the order of 0.1 nanometre. Personalized and individualized genetic testing of DNA from a saliva sample and associated data analysis can provide ancestry estimates down to 0.1% of global population and gene pool (https://www.23andme.com/en-int/). Technological advances place increasingly greater emphasis on precision, perfection and prompt action in many human activities where they are deployed and adopted on a massive global scale. This trend has nurtured a relentless and ever-accelerating pace of work that encroaches on personal time and space, driving ever-greater precision, perfection and immediacy of action. However, truth and beauty associated with imperfection and imprecision, deliberate allocation of sufficient time for relaxation, meandering, exploration and reflection, and the notion that failure and imperfection are a necessary part of the learning process, are also known to be essential ingredients for nurturing artistic creativity and scientific discovery. As technology forces individuals and professions toward greater degrees of precision and perfection in Industry 4.0, what are the consequences for human behaviour in an intrinsically imprecise and imperfect world?

The foregoing complex questions and issues require collective thinking and action across professional, disciplinary, geographical, intellectual and national boundaries. First and foremost, these issues are not just engineering or technology-based issues. They are also strongly predicated on human behaviour. It is perhaps prudent to consider first how human psychology, values, aspirations and limitations will intersect with emerging technologies and their anticipated massive disruptions arising from Industry 4.0. They must include concerns about climate change, sustainability of natural and renewable resources, concentration of as much as 70% of the world population in urban areas and mega-cities, growing inequality in income, wealth and opportunities within and among populations, and the increasing role of machines and their real-time decisions affecting a vast array of routine human activities.

INDUSTRY 4.0 AND LEARNING 4.0: SOME CONSIDERATIONS FOR UNIVERSITIES

Now we consider a few ideas for tertiary educators and universities that could help address some of the issues raised in this paper. Although most of these perspectives are not new, they connect to the challenges discussed above.

A. A critical assessment of the "basic skills" taught in university curricula is needed to prepare students to adapt to a lifetime of technological and societal transformations catalysed by Industry 4.0. Specifically, what special skills does an undergraduate student need to acquire at a university in a time frame that is no longer than four years? What should be the required minimum set of courses and subjects across disciplinary boundaries to prepare the student for a lifetime of re-learning, up-skilling, productive citizenship and a purposeful life? How do different fields as diverse as the arts, humanities, social sciences, business and economics, medicine, natural sciences and engineering assess such needs for basic skills? What is the minimum body of knowledge that a university graduate (an educated person) of the 21st century should possess? As a first step in this direction, Nanyang Technological University (NTU) Singapore introduced minimum course requirements in "digital literacy" (which also includes such topics as ethics in the digital age) for all of its more than 23,000 undergraduate students, beginning with the incoming freshman class of 2018.

B. We briefly examined NAE's 20 greatest engineering achievements of the 20th century and the fourteen grand challenges of the 21st century (see Figure 2 and item 5 discussed earlier). Some would argue that perhaps sufficient attention was not devoted to the integration of technology with human behaviour and with humanity in our collective effort accompanying the rollout of the impressive innovations of the 20th century. Universities could consider formal and informal ways in which such integration routinely becomes part of the education process. This will require tighter coupling of natural sciences, computing, engineering and medicine on the one hand with social sciences, arts and humanities, with topics such as human psychology, communication, ethics, economics, and governance not left out of a broader and more complete curriculum for all students.

C. Mobile technologies and digital information increasingly impact every aspect of human life. Whether a university graduate is an Arts major or a science major, computing and digital technologies will increasingly play a pivotal role in the ability of the graduate to function as a productive citizen of society. Given this trend, computing becomes as much of a "required" subject in a university for an arts or humanities student, as literature and social sciences should be for a student of computer science.

D. It is now widely recognized that rapidly expanding academic disciplines such as artificial intelligence (AI), machine learning (ML), robotics, precision medicine and 3D printing are poised to shape the course of industry in the coming years and decades. However, the impact of these disciplines in shaping the lives and livelihoods of billions of ordinary citizens of the world and in solving some of global society's most pressing challenges has perhaps been less of a focus of academic discourse than its economic and industrial implications. Universities have an opportunity, and some would argue an obligation, to address ways in which the role of these intellectual disciplines could better the lives of under-privileged citizens of the developing world. For example, how can AI and ML advances be used to address the needs of the under-privileged affected by such issues as pollution, job loss, human trafficking, lack of access to clean water, paucity of access to banks and fair lending practices, healthcare, information and basic education?

E. Many governments and industries, along with thinktanks and non-profits, have identified ways in which citizens can receive support and assistance in their efforts to upgrade their work skills. For example, the government of the Republic of Singapore has rolled out the SkillsFuture program (see: https://www.skillsfuture.sg/) to provide its citizens opportunities for lifelong learning outside formal educational organizations and employers. The government has also provided free credits for citizens to incentivize learning. Universities have an opportunity to engage alumni and citizens, from the region and around the world, to tap into opportunities to taking courses and obtaining credit. Many universities have already introduced such mechanisms, from micro-credits to full course credits to online degree programs, with varying levels of success. Nevertheless, there is a critical need to address the issue of aggregating and validating such credits (even for a university's own alumni) that are transportable to employers. This could mirror, with appropriate modifications, pathways for university degrees to be authenticated in many cases by the endorsement of accreditation bodies and governments.

Figure 3– Some strategies for enhancing learning outcomes in Industry 4.0.

F. Finland has emerged as a country that is most resistant to managing misinformation. The approach adapted there involves education in the classroom about real and fake news and training students and citizens about the importance of authenticity of information for the health of society (see: https://www.weforum.org/agenda/2019/05/how-finland-is-fighting-fake-news-in-the-classroom). Universities can play a vital role in this regard by providing proper education about authenticity of information, critical thinking and reasoning, as well as digital literacy and "digital hygiene".

G. Several universities around the world have created multi-disciplinary activities, centres and institutes to address the intersections of science and technology with humanities, human behaviour, policy and ethics in education, research, advocacy and societal outreach. Perhaps only a subset of such institutions, however, have the scope and infrastructure to engage the full spectrum of stakeholders for successfully translating academic pursuit to societal impact. The stakeholder community should inevitably include government agencies, policy-makers, global industry partners, small and medium enterprises, regulating authorities, and non-profits.

Figure 3 provides a summary of some strategies for enhancing learning outcomes in Industry 4.0.

As a step in this direction, NTU Singapore established in 2018 the NTU Institute of Science and Technology for Humanity (NISTH). This university-wide institute is aimed at bringing together the diverse stakeholder community, in partnership with key government agencies and the many industry partners with a major presence on campus, to address a number of issues and challenges. The three areas of initial focus chosen by NISTH are: responsible innovation; governance and leadership in the era of Industry 4.0; and the new urban Asia.

Figure 4– The three initial areas of focus of the NTU Institute of Science and Technology for Humanity (NISTH).

CONCLUDING REMARKS

Scientific discoveries and technological advances are creating unprecedented opportunities for individuals, institutions, governments and global society to elevate living standards and quality of life, and to eliminate disparities. At the same time, history has shown repeatedly that intended benefits of technologies are inevitably accompanied by unintended consequences. With the fourth industrial revolution, rapid pace of technology development and mass adoption, along with instant and borderless communication, offer new opportunities and challenges. Educational institutions, working with governments, industries and nonprofits, play an important role in shaping the conversation on the evolution and eventual impact of Industry 4.0 and in preparing citizens adequately to face the challenges created by the fourth industrial revolution. Whether Industry 4.0 turns out to be a net positive or net negative outcome for the world will critically depend on how technology and innovation, as well as the role of machines in society, are closely integrated with human behaviour and humanity.

REFERENCES

1. The ideas and opinions expressed in this discussion paper have been shaped by the author's involvement as a participant in a variety of panels, forums, discussion groups, symposia and other venues around the globe during the past several years. They have also relied heavily on the author's panel participation and presentations at the World Economic Forum in Davos, his conversations with many thought leaders at these events, and his commencement addresses at a number of universities in North America, Europe and Asia, and his lectures at various national and international conferences. These presentations include: panel discussions at the World Economic Forum Annual Meetings in Davos in 2013-2019; commencement speeches delivered at Indian Institute of Technology Madras, Carnegie Mellon University, Indian Institute of Technology Roorkee, Mangalore University, and National Institute of Technology in Tiruchirapplli, India, and at TEDx@CMU and TEDx@NTU during 2017-2019.
2. Author's lectures delivered at: (a) Times Higher Education Summit on 6 February 2018, Shenzhen, China. (b) High Level Dialogue on ASEAN Italy Economic Relations on 11 April 2018, Singapore. (c) ASEAN Conference 2018 on 3 May 2018, Singapore. (d) 31st CIO Workshop on 15 May 2018, Singapore. (e) InSpreneur2.0 on 31 May 2018, Singapore. (f) TedxNTU Talk on 26 August 2018, NTU Singapore. (g) Tradevents Connect 2018 on 30 August 2018, Singapore. (h) Agency for Science, Technology and Research (A*STAR) Leaders in Science Forum on 4 September 2018, Singapore. (i) Lien Development Forum on 7 September 2018, Beijing, China. (j) RWS 2019 Kick-off Seminar on 17 September 2018, Singapore. (k) Deep Tech Summit on 18 September 2018, Singapore. (l) Magee-Womens Research Summit on 9 October 2018, Pittsburgh, PA, US. (m) QS-APPLE Summit on 21 November 2018, Seoul, South Korea. (n) SingHealth Distinguished Lecture on 13 April 2019, Singapore.
3. Klaus Schwab, *The Fourth Industrial Revolution*. The World Economic Forum, Geneva, Switzerland. https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab.Seealso:https://www.britannica.com/topic/The-Fourth-Industrial-Revolution-2119734.