The Fourth Industrial Revolution and Higher Education

Bryan Edward Penprase (Dean of Faculty, Undergraduate Program, Soka University of America, Aliso Viejo, CA)

The Fourth Industrial Revolution (FIR) is a concept widely discussed at venues such as the World Economic Forum at Davos and within business leadership. Recent white papers describe how the FIR will "shape the future of education, gender and work" (World Economic Forum 2017) and how the FIR will require "accelerating workforce reskilling" (World Economic Forum 2017). A full exposition of the schema and framework of the FIR has been presented in book form, and includes an inventory of some of the emerging technologies that are thought to drive the FIR and some societal implications for this Revolution (K. Schwab 2016). The FIR as a phrase has its roots in early analysis of the evolution of technology where the First Industrial Revolution arose from harnessing water and steam power toward more systematic and efficient forms of manufacturing. Typical descriptions of the First Industrial Revolution include a mention of steam power, which when applied to the mining in Cornwall, and agriculture, brought about massive increases in scale of manufacturing. As one author puts it, steam power "is the hub through which the spokes of coal, iron and cotton were linked" (Rosen 2010). The origin of the term Industrial Revolution itself traces to an 1884 work by Arnold Toynbee entitled *Lectures on the Industrial Revolution* (Weightman 2007). Within Toynbee's description of the Industrial Revolution, the expansion of power and mechanical production only became a revolution from its coupling with a "political culture which was receptive to change" which included shifts in financial arrangements as well as other social progress. As one author puts it, "the Industrial Revolution is not merely an acceleration of economic growth, but an acceleration of growth because of, and through, economic and social transformation." (Hobsbawm 1968). Social and educational transformations from the first three industrial revolutions can provide a starting point in our considering the potential transformations in higher education arising from the Fourth Industrial Revolution.

Educational Responses to the First Two Industrial Revolutions

After the First Industrial Revolution, a vision for a new kind of curriculum began to form with more diverse set of degree options, and a General Education program designed to produce breadth of study through selection of a range of elective courses. This type of education was described by the Harvard President Charles W. Eliot as "The New Education" (Eliot 1869), and offered a dramatic shift away from the dominant classical education eloquently outlined in the Yale report of 1828 (Yale Corporation 1828). University graduate education within the United States and across the world included a widespread adoption of the German university model for postgraduate research, which enabled the rise of dozens research universities within the United States.

The Second Industrial Revolution is generally based in the period from 1860-1900, and is associated with new manufacturing technologies based on electricity (Schurr 1960), which itself triggered additional changes launching what some have described as a "new economy" (Atkeson 2007). An expansion of access to higher education and the proliferation of multiple types of higher education institutions in the United States and Europe gave rise to a surge in discovery and helped consolidate and accelerate the growth brought about by the powerful new technologies. In the United States, the period of the first two Industrial Revolutions brought a large crop of innovative new educational institutions – founded through both public and private funding. The Morrill Act of 1862, passed in the middle of the Civil War and at the beginning of the Second Industrial Revolution, was intended to open educational opportunity "for the industrial classes" and to enable higher education that is "accessible to all, but especially to the sons of toil." These institutions, which took several decades to fully establish in each of the states, were intended to create a steady stream of newly trained technicians and engineers trained in the "practical avocations of life" such as agriculture and the mechanic arts (Geiger 2015). Private philanthropy, fuelled by the immense profits from new industries such as railroads, oil, and steel, enabled the founding of institutions such as Stanford University (1885), the University of Chicago (1890). Numerous small colleges were also founded such as Pomona College (1887), University of Southern California (1880), and a small technical institute known as the Throop College (1893), later to become Caltech. These institutions were founded a few decades after the beginning of the Second Industrial Revolution, and were both enabled by, and responding to the societal and economic changes rapidly building in the end of the 19th century. Most of these new institutions of higher education during the period of the Second Industrial Revolution were co-educational, and helped foster an increased role for women in industrial and academic settings.

It is important to note that changes in society and education from both Industrial Revolutions are also difficult to separate from other causes, such as economic cycles and other titanic geopolitical shifts that came with them, such as the westward expansion and development of the United States, the rise of industrial Japanese and German states and large global wars that dislocated economic activity and accelerated the development of science and technology. Some economists have also observed that the cyclic nature of economic activity arises from regular cycles of economic growth and recession, sometimes called Kondratieff waves (Kondratieff 1935). Spectral analysis of World GDP growth has identified peaks in annual average GDP growth in the period of 1850-1875 and 1895-1913 (Korotayev and Tsirel 2010), which coincides approximately with the conclusion of the first and the beginning of the Second Industrial Revolution. It has been noted by economists that whenever new technologies are introduced into an economy there is a significant lag time for the technology to be fully adopted to a level where they provide measurable impacts on productivity. This lag between technological innovation and growth of productivity has been called a "productivity paradox" and has been attributed to the time it takes for training and experimentation with new technology to widely disseminate throughout society (Atkeson 2007). The results suggest that historically, changes within society and the impacts of technology on education requires time to be fully realized. The profound changes in society and education that arose from the first two Industrial Revolutions spanned several decades, lagging well behind the initial introduction of the catalysing technologies of Steam and Electricity.

This proliferation of new educational institutions and new curriculum after the first two Industrial Revolutions enabled the technical and managerial capacity to implement the massive expansion of the economy and manufacturing that arose in the 20th century. Seismic shifts in US higher education after World War II further advanced the societal changes made possible through the first two Industrial Revolutions. These changes included both a commitment to broader representation within higher education of veterans through the GI bill, and the creation of community colleges in 1947, along with a massive expansion of the research mission of universities through Federal funding. This expansion of research followed the publication of the report commissioned by President Truman entitled *Science: The Endless Frontier* (Bush 1945) resulted in the creation of the National Science Foundation in 1950, which drastically increased the resources available for university scientists, and shifted the incentive structures and curriculum within US higher education for decades to come. Within six years, Federal funding for STEM subjects increased from $6 billion per year to over $35 billion between 1960 to 1966. In the development of its extensive system of 3600 universities and colleges, the United States has created a massive system which enrolls more than 19 million students annually, and grants nearly 3 million degrees with an employment of more than 3.6 million people, including 2.6 million faculty (Gregorian 2014). The higher education system in some ways can be considered as an industry in itself – accounting for more than $380 billion of economic activity, and this higher education system itself is perhaps in need of an "Industrial Revolution."

Educational Responses to the Third Industrial Revolution

If history is to be our guide, the Third Industrial Revolution, which is generally attributed to computerization and web-based interconnectivity developed in the 1980's and 1990's, is only now having its rippling effects upon society, politics, economics and education. Within the Third Industrial Revolution, the expansion of access to higher education rose to even greater prominence with greatly increased diversity on campuses, and globalization of academic research accelerated by online technologies. An intensified commitment to large scale higher education across the world has resulted in increasing rates of higher education within populations in India, China as well as in the United States. For example, in the US the fraction of the population with some access to higher education has risen from 4 percent in 1900 to nearly 70 percent in 2000. The increasing diversity within student populations is also remarkable, with a 30 percent rise in enrollments in underrepresented groups, resulting in 38 percent of US college enrollments.

One of the largest ripples from the Third Industrial Revolution was the move toward online education, which culminated in the "Year of the MOOC" during 2012 as massive online open courses offered to completely displace traditional in-person higher education, and expand access to university education to millions of previously unserved students across the world. The revolution of higher education brought about by online courses is still ongoing, but is likely to result in less of a displacement and more of a hybrid integration of the best of in-person "high-touch" kinds of higher education with empowering online technologies to enable students to more rapidly build skills and knowledge asynchronously. One author has suggested a useful framework of "disaggregating" higher education activities between those that are intrinsically synchronous and personal, such as personal exploration, coaching and mentorship, from those activities that can be easily scaled and shifted online such as content transfer, and authoring and production (Staton 2012). Within the environment of increasing online content delivery and access to information, these more personal components of the educational experience will become of increasing value and will not be easily replaced by technology.

Online and tech-enhanced teaching within universities is enabling both research universities and liberal arts colleges alike to more efficiently teach students with diverse backgrounds, and to open up their campuses to a more global community of both faculty and students. Small liberal arts colleges are working together to realize economies of scale and to employ new types of technologies that improve on-campus experience for students through online math courses for incoming students, language courses taught via videoconferencing, and new ways of merging social media with small class seminars. One example of an initiative of this sort is the Liberal Arts Consortium for Online Learning (or LACOL), which has brought together some of the leading US liberal arts colleges to explore these technologies (LACOL 2017). Online education companies such as Coursera and EdX are partnering with larger universities to create newer and more interactive formats for their online courses, and also are developing dozens of new "stackable micro credentials" that link multiple online courses with in-person consultations with faculty and opportunities for students to conduct significant original capstone projects (Young 2017).

The Third Industrial Revolution has brought educators to an environment where access to information is immediate and free, shifting the focus toward "active learning" pedagogies that place a premium on collaboration within diverse teams in a project-based and peer learning environment (Mazur 2009). Many of the most thoughtful responses to "reform" in STEM education in recent years have resulted in a greater emphasis on liberal arts and interpersonal skills imbedded within a more interdisciplinary curriculum. Examples include the Project Kaleidoscope Science initiative (Elrod and Kezar 2016), Liberal Studies in Engineering (Bucciarelli and Drew 2015), the American Physical Society SPIN-UP project (Hilborn, Howes and Krane 2003), the HHMI Scientific Foundations for Future Physician report (AAMC 2009) – which all emphasize more interdisciplinary approaches in STEM that develop student capacity for collaboration and social interaction within STEM courses and curriculum.

Larger scale responses in recent years to changing realities in the world have also resulted in entirely new institutions created with more global and more interdisciplinary curricula and a greater emphasis on strong collaborations that can arise between students within a residential living context. One example includes the Yale-NUS College in Singapore, which was developed by Yale University and the National University of Singapore to provide a full residential liberal arts college within Asia including an interdisciplinary curriculum which features literature and philosophy from both Eastern and Western cultures, a range of interdisciplinary science courses and quantitative reasoning, and wide-range courses in Modern Social Thought and Comparative Social Institutions that enable students to collaborate and discuss some of the deepest issues of identity, family and social responsibility within the emerging globalized world of the 21st century (Penprase and Nardin 2017). A remarkable curriculum at Soka University of America in California develops students to become "global citizens" through intensive language study and required study abroad in a foreign language, as well as with wide-ranging Core courses that explore "Enduring Questions" of humanity and our social context, drawing from class works of Chinese, Indian and Greek philosophers, European social theorists, and modern interpretations of 21st century society in both the US and Asian contexts. Courses in both American Experience and the Pacific Basin and Modes of Inquiry further develop student capacity for discussion, dialog and reflection within an international context (Soka University of America 2017). A third curriculum being developed by Duke University for its new Duke-Kunshan University in China explores the concept of "rooted globalism" which blends an appreciation for a local culture with a wide-ranging exploration of international approaches to identity and society, and develops a framework for liberal arts in China in the 21st century (Godwin and Pickus 2017).

Emerging Realities from the Fourth Industrial Revolution

The Fourth Industrial Revolution often is described as the result of an integration and compounding effects of multiple "exponential technologies", such as Artificial Intelligence, biotechnologies, and nanomaterials. One example of the emerging reality within the FIR might be the development of synthetic organisms (life from DNA created within computers and "bio-printed") manufactured using robotic assembly lines, where nano-materials provide immense improvements in the efficiency of production. The FIR extends the paradigm of Industrial Revolution into a future when many of the elements of what we might consider "industry" – fixed and centralized factories, massive labour forces within large corporations - will no longer exist. The most obvious exponential technology is the exponential increase in computer power and cost in storage, which obeys a geometric relation commonly known as "Moore's Law." The doubling of CPU power every 18-24 months has enabled new supercomputers to reach computation speeds of 300 quadrillion FLOPS (floating operations per second) in the latest supercomputer known as Milky Way 2 (Peters 2017), an increase in speed of more than a factor of 300,000 in just two decades. When these digital exponential technologies are combined with other similarly rapidly expanding technologies – biotechnology, nanotechnology, and artificial intelligence, the combination of multiple exponentially developing technologies compounds and multiples the pace of change. Some have described the convergence of these "exponential" technologies as providing a "Singularity" – which will provide untold benefits to humanity, as humans "transcend biology" according to some authors (Kurzweil 2005).

The WEF has defined a set of "tipping points" at which the technologies of the FIR will become widespread enough to create massive societal change. These tipping points include the proliferation of FIR technologies to levels where they make significant impacts on our lives and require shifts in employment and education. A survey of 800 high tech experts and executives determined a series of dates by which tipping points would be reached. Examples include implantable cell phones by 2025, 80% of people with a "digital presence" by 2023, 10% of reading glasses connected to the internet by 2023, 10% of people wearing internet connected clothes by 2022, 90% of the world population with access to the internet by 2024, 90% of the population using smartphones by 2023, 1 trillion sensors connected to the internet by 2022, over 50% of internet traffic directed to homes and appliances by 2024, driverless cars making 10% of all cars in the US by 2026, and many other outcomes such as AI members of the board of directors, Ai auditors and robotic pharmacists, proliferation of bitcoin in the economy, 3D printed cars by 2022, transplants of 3D printed organs such as livers by 2024, and several others (World Economic Forum 2015).

One author has described the Fourth Industrial Revolution as a shift from non-renewable energy resources toward renewable energy enabled by bio-technology breakthroughs. This approach preserves the simplicity of the Industrial Revolution as Energy Source paradigm, and makes concrete predictions about the emerging 'bio economy' that will fuel the future (Philp 2017). Noting that more than 50% more food will be needed by 2050, within a context of degraded capacity from soil degradation and global climate change, the FIR places an imperative on developing revolutionary new sources of food production. The emergence of "bio refineries" to use genetically modified microbes to provide a wide variety of useful chemicals as well as food components could be an essential part of the FIR landscape. These bio refineries could make use of flexible food stocks that might include cellulose, biomass, and simple sugars, to enable mass production of a diverse range of fuels, pharmaceuticals and food products in extremely large quantities and enable a reduction the use of fossil fuels in the coming decades. Such organisms could also be used for environmental mitigation by removing various compounds from the environment such as toxic metals within landfills. Start-up companies are designing new organisms using standardized synthetic biology "wetware" allowing for the development of biological circuits and computers, and even for building materials to be "grown" using living materials known as "bio-bricks" (Cameron, Bashor and Collins 2014).

The FIR may also enable a technological solution to the environmental threats arising from the buildup of CO_2 and other greenhouse gases from the massive factories arising from our first two Industrial Revolutions. Some authors have predicted that global warming could render the earth uninhabitable through an increase of more than 10 degrees, which would result in widespread crop failures and large fractions of the world's populations subject to heat exhaustion and potential death. The increases in temperature reduce agricultural productivity – by as much as 15 percent for every degree of warming (Wallace-Wells 2017). New technologies could help absorb excess CO_2 using both bio-engineered organisms, and new materials within buildings that can absorb CO_2.

In the new manufacturing regime enabled by FIR technologies (sometimes called the Internet of Things or IoT) nearly anything can be designed on a computer and then "printed" on 3D printers that create objects in countless materials, or even biological tissues. This capability will allow humans to turn "data into things and things into data." Materials used can include the familiar thermoplastics found in traditional 3D printers to large scale construction materials to clumps of atoms 10nm across (Gershenfeld 2012). This capability will enable printers to construct entire buildings, build microstructures with incredibly precise tolerances or create of biological structures for implants or even transplants of organs.

Higher Education's Response to the FIR

The exact impacts of such Fourth Industrial Revolution technologies on society and the planet are still unknown – but the fact that they will bring profound and rapid change seems all but certain. The need for higher education to respond is urgent as the power of all of the technologies for either positive social impacts or devastating environmental damage is upon us, as is the potential for irreversible loss of control over networks of powerful artificial intelligence agents with increasing autonomy within financial sectors, and within urban infrastructure.

Substantial changes to the science and technology curriculum would be a reasonable strategy, to allow for students to develop capacity in the rapidly emerging areas of genomics, data science, artificial intelligence, robotics and nanomaterials. Such a FIR STEM curriculum would reconsider the curriculum within the traditional "primary" sciences – biology, chemistry and physics, and place a higher premium for training in computer science subjects as a form of FIR literacy. Within biology, new approaches might include training within introductory courses to discuss emerging areas such as synthetic biology and molecular design. Some examples of reshaped Life Science curriculum can be found at Stanford University, where a new Problem Solving in Biology course has students design cures to real-world pathogens such as Lyme disease and HIV, using authentic data from scientific literature and experiment design (Cyert 2017), or a new course in Engineering Biology that allows students to design their own life forms on computers and "bio-print" them to solve practical problems such as curing diseases and environmental mitigation. These courses are a response to the emerging bio-economy which already exceeds $400 billion in the US alone (Endy 2016). Within the Stanford curriculum is now an entire new major known as Bioengineering, which trains students at the "interface of life sciences and engineering" and merges expertise and resources in the departments of Medicine, Biology and Engineering (Abate 2015). Similar innovations within chemistry include a worldwide proliferation of courses and degree programs in "Green Chemistry" which blends chemistry, biology and environmental science to allow students to engage on real environmental problems such as synthetic fuels, bioplastics, toxicology, and to train students in techniques to reduce pollution (Mammino and Zunin, V.G. 2015). New physics curriculum that emphasize FIR collaborative skills are being developed, where the curriculum is centred on projects where students design and build original musical instruments, cryptographic gadgets, and other inventions collaboratively (Perry 2013). Additional educational responses to the Fourth Industrial Revolution would be to retool STEM curriculum and institutions to provide new science programs and departments in emerging interdisciplinary fields to more efficiently provide trained workers to help advance and accelerate the development of ever-more sophisticated biotechnology, nano-technology materials, and artificial intelligence.

Any educational plan for the Fourth Industrial Revolution must be built upon the results of the Third Industrial Revolution described above, with its emerging development of hybrid online and in-person instruction, and efficient and seamless integration of global videoconferencing and a wide array of asynchronous educational resources. Blended instruction, and optimization of the "flipped" class, and online courses will make more efficient learning environments for students that can adapt for diversity in preparation within students. The Future of Education Report at MIT strongly emphasizes the need for leveraging online courses to strengthen the residential education for undergraduates, and to also give more flexibility and modularity of courses (MIT 2013). Examples of effective blended environments include the supremely popular CS 50 course at Harvard (Mendez 2014), the MIT introductory Electrical Engineering course, where course material is delivered entirely online with the in-person component focusing on laboratory and maker space time for students to build and test robots, and the MIT Circuits and Electronics course, which has been offered as an online course for residential students, who found the course to be less stressful, and who appreciated the ease of scheduling and additional speed for receiving feedback in their assignments (Roll 2017).

Such a Fourth Industrial Revolution education strategy must also include in equal measure a deep consideration of the human condition, the ways in which technologies and shifting economic power impact people of all socioeconomic levels, and the threats that exist within a world that is increasingly interconnected without deep intercultural understanding and an abiding respect for freedom and human rights. These approaches favour the interdisciplinary and global curriculum in a residential context, such as is found in liberal arts institutions. These approaches maximize the level of intercultural and interpersonal skills, which will be a hallmark of the FIR.

Fourth Industrial Revolution Liberal Arts - An Ethical Imperative for our new Human Condition

More than anything, the Fourth Industrial Revolution puts a premium on adaptability and in self-directed learning and thinking. Some authors have noted that the “shelf life” of any skill in the present-day environment has become increasingly short, requiring future workers to continuously update their skills and tech themselves about new technologies and even industries that may not have existed while they were being trained for their initial degrees. A further design requirement for education within the Fourth Industrial Revolution would be to include a strong overlay of ethical thinking, intercultural awareness, and critical thinking to enable for thoughtful and informed application of the exponentially developing technologies. A well-developed plan for a FIR form of higher education will insure that our students will graduate into a world that they can help shape with wisdom and skill, while building a future society we would want ourselves and our grandchildren to live in. Graduates of any FIR higher education should be capable of advancing the material culture of our future world, while creating a culture which advances technologies sustainably and ethically.

Within Career and Technical Education (CTE), new frameworks need to be developed to respond to the increasing rate of change, the complexity and the volatility of employment. Such educational programs will need to shift emphasis away from routine tasks, and like the more academic curriculum, develop habits of mind and capacity for creativity within workers at all levels. One such framework for CTE suggests that an emphasis on soft skills such as Career Navigation, Work Ethic, and Innovation will better prepare students for the emerging FIR workplace (Rojewski and Hill 2017). Integration of other FIR technologies, such as the Internet of Things (IoT) in both CTE and more academic settings, requires a simultaneous treatment of the rapidly changing technical details, and building of capacity for teamwork and collaboration.

The changing nature of work – which favors more flexible and shorter-term assignments, has been cited as a key factor to address within FIR education. Future jobs within the FIR technology sectors, artificial intelligence, machine learning, robotics, nanotechnology, 3D printing, genetics and biotechnology, are expected to dominate in the coming decades. Within those sectors employers and industries are projecting that social skills that include persuasion, emotional intelligence and capacity for teaching others will be at a premium (World Economic Forum 2016). Already employers have recognized the power of liberal arts for catalyzing entrepreneurship, and for developing “people skills” which many large tech companies are actively seeking to help them develop new products and new marketing (Anders 2017).

Fourth Industrial Revolution Liberal Arts – New Elements to the Curriculum

The Fourth Industrial Revolution and its associated technologies such as biotechnology and artificial intelligence challenge some of our fundamental assumptions of what it means to be human, and the conditions of our relationship with the natural world. How should liberal arts respond to this new Human Condition? There are several key pieces that seem to be integral to a Fourth Industrial Revolution Liberal Arts Program.

The social dislocations from the FIR have to be accounted for within a new curriculum. Already we have seen the correlation between corporate earnings, productivity gains, and wage increases break down, and as smart AI-powered machines and other advanced technologies become more common within corporations, this trend is only expected to accelerate. The FIR curriculum needs to respond to the political and social dimensions that will accompany the increasing centralization of wealth and political influence. As described in one of the WEF reports, the political effects of expansion and convergence of the physical, digital and biological worlds will be profound. This development will “enable citizens to engage with governments, voice their opinions, coordinate their efforts, and event circumvent the supervision of public authorities. Simultaneously, governments will gain new technological powers to increase their control over populations.” (K. Schwab 2016)

With the evolution of online instruction and expanding uses of artificial intelligence, new guidelines are needed to provide a theoretical basis for digital pedagogy. Some have called the old models of teaching Anthropocentric Humanism, and the new types of digital education "Critical Posthumanism." These approaches stress that digital education is more than a purely technical concern, as it changes the dynamics of space and creates new types of learning cultures that challenge our notions of what it means to be human (Bayne and Jandric 2017). Such a curriculum can also help students grapple with the complex issues of relationships within online spaces, and the philosophical dimensions of artificial intelligences that may approach or even surpass human intelligence. One author has created a "Cyborg Manifesto" to help explain the social reality for a cybernetic organism, which would be a "creature in a post-gender world" where divisions between nature and culture, public and private, and human and non-human break down (Haraway 2000). These humanistic concerns are inseparable from technical advancement, and a new FIR curriculum will need to reduce the divisions between humanities and STEM to create a more integrated "system" of education which can explore the newly emerging conceptions of self and identity within the FIR, including discussions of autonomy, free well, genetic vs social determinism. The changing nature of social relations and interactions – social media, obligations to identity groups, society, nation and world also needs to be central in the FIR curriculum as all of these identities and loyalties are shifting rapidly due to increased globalization.

More than ever, higher education in the FIR age must develop capacity not just for analyzing and breaking a technical or scientific problem into its constituent parts, but must instead emphasize the interconnections between each scientific problem across global scales, and interrelations between physical, chemical, biological and economic dimensions of a problem. As one author has put it (Peters 2017), "there is a single planetary technical system" in which globally scaled markets enable "hundreds of thousands of transactions and information exchanges take place at the speed of light within the space of a microsecond." This speed can cause volatility and chaos in financial systems, and similar analogs of interconnected complex systems exist in the realms of marine ecology, forest conservation, global climate and the impacts of extinctions on the biosphere, to name a few examples. In all of these systems the rapidity of responses to the system and the larger network of interconnections can easily result in exponential responses to small perturbations, and the FIR curriculum needs to be train students to recognize and help manage the proliferating numbers of exponentially responding systems.

New Sequencing of Education to Renew Skills

In addition to the more reflective residential education settings described above, the rapid pace of change within the FIR will require rapid expansion of existing initiatives for updating skills after graduation, and re-connecting within older workers in campus environments. Within scientific and technical education, we will need educate and re-educate students to help develop and shape the use of today's most rapidly emerging technologies. Pathways for students to re-engage with their institutions after graduation will become imperative, and will provide both updated skills to workers, and a new channel for younger students (and faculty) to engage with the rapidly changing realities within the industrial and corporate sectors. One innovative initiative exploring new sequencing of higher education is the Stanford2025 project, which envisions several mechanisms whereby students can extend their education over longer timeframes. One model is the "open loop university" where students can experience six years of higher education over their entire adult careers that can allow them to blend their learning with life experience and provide value to the campus by returning as "expert practitioners" over several intervals – enabling students to refresh their skills while interacting with the campus community. Another model known as the "axis flip" prioritizes skill development and competency training over content and disciplinary topics, requiring new methods of assessment and a degree known as a "skill-print" that students would constantly renew and extend through their careers (Stanford2025 2013).

The hallmark of the FIR is exponential growth and rapid change, which gives the curriculum an imperative to update the content on an unprecedented frequency to match the rapid tempo of scientific and technological advances. A more responsive curriculum of this sort places an extremely high premium on faculty development and curriculum renewal, as well as the mandate to create students that can think and reinvent themselves within the changing world they will graduate into. Within future universities and colleges, both students and faculty will never be "done" with their educations, but instead must engage constantly with their colleagues and outside expertise and experience to frequently renew and update their skills. To enable faculty to be able to maintain current knowledge, more active and creative forms of faculty development will also be required, and the campus must become a constantly renewing collaborative hub of activity to maintain itself within the fast-paced FIR environment of the future.

Conclusions

The first three Industrial Revolutions provided evidence for the profound shifts in society, the economy and in education which resulted in a proliferation of curricular innovation and the establishment of new educational institutions. As in the previous Industrial Revolutions, the most profound effects of this Fourth Industrial Revolution on our society will not be realized for many decades. Unlike previous of these Industrial Revolutions, however, the FIR features the impacts of several compounding "exponential technologies" which all share the capacity for rapid increases in scale and reductions of cost. This rapidity of advance in technologies demands a more proactive response from the educational sector than the more gradual societal evolution and subsequent response from educational institutions present in earlier Industrial Revolutions.

The impacts of the emerging FIR technology in economic and environmental terms alone will require a drastic reconsideration of the curriculum within higher education, to enable students to comprehend both the individual technologies in detail but to be able to thoughtfully analyze and predict the evolution of networked systems of technology, environment and political systems. The dynamic responses with networked systems – and the exponential feedback effects can amplify the pace of change, as has been seen in the context of global climate change, and in many other physical and biological contexts. The STEM curriculum will need to focus on emerging technologies – robotics, AI, IoT, nanomaterials, genomics and biotech – to provide not only a workforce capable of developing new applications and products, but capable of interpreting the effects of these technologies on society, and using their training to provide sustainable and ethical uses of science and technology. More than any particular content area, curriculum needs to help students develop capacity for ethical reasoning, for awareness of societal and human impacts, and to be able to comprehend the impacts of FIR technologies on people and to act towards improving not only our material prosperity, but our social and cultural fabric. From strictly economic terms, students who are capable of creative insights, collaborating in diverse teams, and navigating through global cultural differences will be at an advantage in a workplace where the meaning of skills will become more of interpreting rapidly changing information and being able to work with experts and stakeholders toward common understanding of the benefits of sustainable development. While earlier industrial revolutions have prioritized some of the raw materials needed to fuel their factories or cities – placing a premium on capital based on land, water power, coal, oil and wood – the FIR will place a premium on intellectual capital, and in capacity for collective thought. Students who are able to learn in residential environments with diverse colleagues, and develop solutions together in teams in their classes will be well trained for the types of tasks that will be asked of them in the FIR. Our Colleges and Universities owe it to these students and our future to develop more interactive forms of pedagogy at all levels, and to embrace a curriculum that stresses perspectives from multiple disciplinary and cultural perspectives over static swathes of disciplinary "content" and that cultivates creative discernment and communication over mastery of skills that are subject to obsolescence. Many of the emerging liberal arts institutions in the US and Asia, and new types CTE curricula are providing useful examples of how to implement this a new model of FIR higher education. Higher education needs to recognize the necessity of adapting these new FIR forms of education to assure the sustainability of our environment and economy, as well as to sustain the relevance of higher education as a responsive and vital component of society's response to the FIR. Taken together, these new forms of FIR education will prepare both students and faculty for leadership roles in a world of rapidly accelerating change, with a curriculum that develops both technical mastery and a deep awareness of ethical responsibility toward the human condition.

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