Educational Strategies and Challenges for 4IR and Beyond

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Our future educational and work strategies need to be crafted by taking account of the unique context of the century in which we live. We have been living in a time of unprecedented change and technological advances. In recent years the digital technologies of the "computer revolution" have been joined by other new technologies that offer equal or greater potential to transform our economy, our workplace and also our institutions of higher education. Like computer technologies, the technologies of the co-called Fourth Industrial Revolution (4IR) will expand exponentially. This paper will consider some of the outlines of each of these technologies and describe how they may shape the future of Higher Education and Jobs of the Future. Within these 4IR technologies will arise future industries, challenges to our notions of society, citizenship and even our humanity, and these challenges will need to be answered by our students and future graduates. The 4IR can serve well as a blueprint for a future higher education curriculum, which when combined with liberal arts disciplines in the humanities and social sciences and directed toward problems facing our world, can help assure a sustainable and peaceful future. .

The Fourth Industrial Revolution (FIR) has been discussed at the World Economic Forum in Davos and within business strategy circles as the underlying economic reality of our current century. This reality will radically "shape the future of education, gender and work."[1] A thorough description of the FIR has been presented in book form[2], and another recent volume describes the many ways that the FIR will affect higher education.[3] The FIR paradigm was developed through an awareness of the sequence of technologies in energy and manufacturing that transformed society in the past three centuries. The notion takes inspiration from the first Industrial Revolution in the 18th century, which arose from harnessing steam power to transform manufacturing. This change in energy generation radically disrupted the economy and society throughout the 19th century. Similar changes came about in higher education a few decades later with new breadth of study and elective courses introduced at Harvard in what its President then called "The New Education."[4] This first industrial revolution created a dramatic shift away from the dominant classical education eloquently outlined in the Yale report of 1828 and allowed for higher education to respond to the needs of the rapidly evolving economy and society.[5]

The Second Industrial Revolution similarly arose from transformations in the world coming from a new energy source, that of electricity, which in the late 19th century enabled new manufacturing technologies and opened up cities to skyscrapers with newly developed electric elevators, enabled

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[1] World Economic Forum. 2017. *Realizing Human Potential in the Fourth Industrial Revolution - An Agenda for Leaders to Shape the Future of Education, Gender and Work.* White Paper, Geneva: World Economic Forum.
[2] Schwab, K. 2016. *The Fourth Industrial Revolution: what it means and how to respond.* Global Agenda, Geneva: World Economic Forum.
[3] Gleason, N.W, ed., 2018, Higher Education in the Era of the Fourth Industrial Revolution, Palgrave:London.
[4] Eliot, Charles L. 1869. "The New Education." *The Atlantic,* Feb. 1869.
[5] Yale Corporation. 1828. *Reports on the Course of Instruction in Yale College.* New Haven, CT: Yale Corporation.

new types of transportation, and opened cities to night-time activity.[6] The impact of these innovations triggered massive changes in industry launching what some described as a "new economy."[7] Alongside economic changes came dramatic changes in education, as the US and Europe began a massive expansion of universities adopting the German university model for postgraduate research. During and after the Second Industrial Revolution, many new research-intensive universities such as Stanford, Caltech, and the University of Chicago were launched, featuring new types of curriculum that included both specialized research courses and new Core Curricula that focused on the humanities and the sciences. Many of the features of the modern 20th century university, such as General Education courses, majors, and widespread access to specialized degrees in STEM subjects came about from this period, along with an increasing emphasis on research and graduate education within university campuses.

The Third Industrial Revolution and its impacts on Higher Education

The Third Industrial Revolution, which arose from the massive growth of computation and the development of the world-wide web, began in the 1980's and is still profoundly affecting society, politics, economics and education in the early 21st century. Global supply networks, the widespread use of video teleconferencing, and increased collaboration with workers and researchers around the world were instantly enabled through the internet. Access to information was made immediate and free through the world-wide web, which dramatically reduced the costs for gathering facts and accessing millions of volumes of books and journals from the world's libraries. Alongside this Third Industrial Revolution came a massive transformation of education which is still being developed. Changes in education included increased of access to higher education through online courses, eased collaboration and communication across the earth to provide for distributed research and teaching across the world's universities, and new partnerships made possible by the improved communication and interconnectivity of the modern internet-based world.

The most visible of these changes from the Third Industrial Revolution is the growth of online education. The rise of new massive online open courses (MOOCs) has made higher education available to literally millions of students who were previously unable to access universities. With improved software and over a decade of experimenting with online education, new types of degree programs and more effective hybrid courses are boosting the efficiency of our universities and transforming how students develop skills and knowledge both within campuses and from their homes and workplaces. Partnerships between universities and online education companies such as Coursera and EdX have enabled technology to provide more interactive forms of online education as well as dozens of new "stackable micro-credentials" and online degree programs. The new forms of online learning can link multiple online courses with in-person consultations with faculty and provide opportunities for students to conduct significant original capstone projects.[8] After several decades since the beginning of the Third Industrial Revolution, students and professors

[6] Schurr, S.H., et al. 1960. *Energy in the American Economy, 1850-1975: An Economic Study of its History and Prospects.* Baltimore: Johns Hopkins University Press.

[7] Atkeson, A., and Kehoe, P. 2007. "Modeling the Transition to a New Economy: Lessons from Two Technological Revolutions." *American Economic Review* 64-88.

[8] Young, J.R. 2017. *The New Frontier in Online Education.* Slate. October 10, 2017, available at: **http://www.slate.com/articles/technology/future_tense/2017/10/microcedentials_are_the_new_frontier_in_online_education.html** Accessed Jan. 17, 2019.

now enjoy an environment where the emphasis of teaching is less on delivering content and factual knowledge and instead is focused on new kinds of "active learning" pedagogies that place a premium on collaboration within diverse teams in a project-based and peer learning environment.[9] Many of the most exciting innovations in STEM education in recent years have been made possible by the greater emphasis on interdisciplinary work and collaborative learning imbedded within newly developed active learning environments.[10]

Another exciting outgrowth of our current Industrial Revolution, like earlier industrial revoluitions, is in the form of new universities and colleges. These institutions, reflecting the nature of our current age, feature more global and interdisciplinary curricula with a greater emphasis on strong collaborations between diverse groups of students housed within a residential living context. Examples include the NYU Abu Dhabi campus, which has provided a unique global form of liberal arts for students from across the world in UAE. Its mission and vision include a consideration of the "essential roles and challenges of higher education in the 21st century" which includes a liberal arts education situated within a research university that provides benefits to its society, and to educating students "who are true citizens of the world." The campus of NYU Abu Dhabi is also envisioned to be a "pioneering a new model of higher education for a global world, dedicated at once to excellence in teaching and research and to advancing cooperation and progress on humanity's shared challenges." [11]

Another example of a new institution for our age is the Yale-NUS College in Singapore, developed by Yale University and the National University of Singapore. Yale-NUS was designed to provide a residential liberal arts college within Asia with an interdisciplinary curriculum that draws from both Eastern and Western cultures. The Yale-NUS curriculum includes wide-ranging common experiences and interdisciplinary courses taken by all students that give all students deep knowledge in humanities, social sciences, and sciences. At its root the Yale-NUS College is also based on "a focus on articulate communication," "open, informed, and reflective discourse," and "conversation" between individuals. The Yale-NUS College curriculum report of 2013 describes the goals of the new curriculum:

> *"Among the goals of a college curriculum is to help students make sense of that experience together, through a set of conversations about some of the most fundamental questions and problems of human existence. The curriculum should facilitate conversation, as would the campus design, with its carefully engineered common spaces. Fundamental questions would be posed within team-taught common courses that transcended East and West and blended individual academic disciplines in new and innovative ways."*[12]

The Yale-NUS Curriculum features an ambitious and interdisciplinary Common Curriculum that includes two semesters of Literature and Humanities, two semesters of Philosophy and Political

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9 Mazur, E. 2009. "Farewell, Lecture?" *Science* 323: 50-51.

10 Penprase, B.E., 2020, *STEM Education for the 21st Century*, Springer, Inc:Dordrect

11 NYU Abu Dhabi, "Mission and Vision," available at https://nyuad.nyu.edu/en/about/nyuad-at-a-glance/vision-and-mission.html, accessed Jan. 9, 2020.

12 Garsten, B., et al, "Yale-NUS College: A New Community of Learning," Curriculum Report accessed at http://www.yale-nus.edu.sg/wp-content/uploads/2013/09/Yale-NUS-College-Curriculum-Report.pdf

Thought, a course entitled Comparative Social Inquiry and another Modern Social Thought course. It also includes Quantitative Reasoning, and two semesters of Scientific Inquiry courses.

As a final example, I include my own institution, Soka University of America (SUA) in California, which was founded in 2001 to enable students to become “global citizens committed to leading a contributive life” 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 the “Enduring Questions within a Social Context.” These Core courses draw from classic works of civilizations from across the world, as well as from more modern authors and philosophers exploring timeless issues of identity, ethics and morality. The SUA required courses also include Modes of Inquiry, American Experience, and Pacific Basin to allow for a consideration of how we determine truth, how power and marginalized communities vie for power in the American context, and how the civilizations of the Pacific Basin have interacted socially, economically and culturally. SUA students take a diverse array of courses across humanities, social sciences and sciences, and SUA is developing a new interdisciplinary Life Sciences programs to prepare students for 21st century careers in biotechnology and health sciences. The SUA campus also includes students from over 40 different nations and requires all students to develop an original capstone project.[13] One of the main goals for SUA is for fostering a more peaceful world. This commitment has been described by SUA’s founding president, Danny Habuki, as follows:

> *“SUA is committed to providing students with an educational opportunity that fosters love for humankind, develops character, provides an intellectual basis for the realization of peace and empowers learners to contribute to and improve society.”*[14]

All of these young 21st century institutions, like the new institutions of the 20th century, arose from the changing conditions of the times, and enable students to be prepared for these shifting realities through new forms of higher education. From this brief survey of history, it is clear that each industrial revolution was followed by a revolution in higher education some 10-20 years after the economic transformation has taken hold. If history is to be our guide, our present revolution, known as the Fourth Industrial Revolution, will have similar transformative effects, and as educational leaders we need to be prepared to respond rapidly to enable our institutions and nations to be fully equipped to not only benefit from the technological advances, but to train leaders who can create technology that will ethically and sustainably enhance society and that harness these technologies to solve many of the “global grand challenges” that face our planet.

The Fourth Industrial Revolution and its Exponential Technologies

Our current Fourth Industrial Revolution is often described as the result from the integration and compounding effects of multiple “exponential technologies,” such as Artificial Intelligence, Biotechnology, the Internet of Things and Nanomaterials. Each one of these technologies individually has the capacity for scaling exponentially and revolutionizing our economy and society. Our higher education institutions and societies need to be ready for this transformation, since unlike earlier IR’s this revolution may occur not over several decades but within 5-10 years. We should also consider one additional new technology in the mix, quantum computing, which

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[13] Soka University of America, Campus website, http://www.soka.edu , accessed Jan. 9, 2020.
[14] Habuki, D., 2019, Soka University website, http://www.soka.edu , accessed Jan. 9, 2019.

just recently was announced to have achieved "quantum supremacy" in which the quantum computer can solve now problems that conventional digital computers might take 10,000 or more years to solve.

Moore's Law describes how our computer CPU power doubles every 18-24 months, with corresponding decreases in costs. This progress 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, an increase in speed of more than a factor of 300,000 in just two decades.[15] With digital computers, information is encoded in a series of "bits" or binary information, while quantum computers encode data in quantum bits or "qubits" which are packets of matter behaving in a very quantum mechanical way – as waveforms of probability.

Unlike the bit, which encodes a microscopic bit of information, the qubit is able to provide much richer information since the waveform can simultaneously include vast structure and detail which all is operated upon at once. A recent paper published in the prestigious journal *Nature* reported results from a 53-qubit quantum computer that completed a problem in 200 seconds that would take a state-of-the-art classical supercomputer approximately 10,000 years.[16] The quantum computer make use of quantum effects such as superposition, entanglement and interference to explore a huge parameter space and instantly converge on a solution, or solutions, to a problem. Once the number of quantum bits rises above a medium level, these devices achieve "quantum computational supremacy."

John Preskill, one of the leaders of quantum computing who coined the term "quantum supremacy" explained in a recent article that we are currently in the age of the "noisy intermediate-scale quantum" (NISQ) machine, which are able to calculate much faster than classical digital computers on very specific kinds of problems, but that in 30 years or so such quantum computers will be widely available for more general problems.[17] Quantum computing offers the possibility of computers millions or even billions of times faster than our best digital computers, which if coupled with new Artificial Intelligence algorithms, could create computers that would achieve either "General Intelligence" (the intelligence of a human being) or even "Super Intelligence" (whereby computers exceed human intelligence by thousands or millions of times).

One of the risks of the full-fledged development of AI is the acquisition of "Artificial Super Intelligence." While AI currently beats human beings in logical tasks with tight constraints (such as in the games Go and Chess), Super Intelligence refers to a time when AI agents are able to outperform humans in all respects, including complex tasks with minimal constraints and instructions. In this regime, as in current Machine Learning algorithms, the AI agent learns from experience and continuously improves on its own. As the AI agent progresses in its learning, it

[15] Peters, M. 2017. "Technological Unemployment: Educating for the Fourth Industrial Revolution." *Journal of Self-Governance and Managment Economics* 5 (1): 25-33.
[16] Arute, F., 2019, et al, "Quantum supremacy using a programmable superconducting processor," *Nature*, 23 October 2019, available at **https://www.nature.com/articles/s41586-019-1666-5,** accessed Jan. 9, 2020.
[17] Brooks, M., "Beyond Quantum Supremacy: The Hunt for Useful Quantum Computers," Scientific American, Oct. 3, 2019, available at https://www.scientificamerican.com/article/beyond-quantum-supremacy-the-hunt-for-useful-quantum-computers/, accessed Jan. 9, 2020.

may even develop the capacity to rewrite its own code and to defy efforts by humans to restrain it or slow down its growth in intelligence or capacity.

Some have labelled the paired promise and peril of AI as the Singularity Paradox, which describes the peril of AI equipped with unlimited intelligence but limited wisdom. This can be concisely described as "the danger of super-intelligent machines is that they are too stupid to have common sense." Such a Super Intelligent AI agent may create dangers from single-mindedly pursuing its goals with increasing sophistication and speed. One example is an AI agent programmed to maximize paperclip production that unintentionally destroys the earth as it converts all available matter into paperclips, defying all attempts to stop it.[18] Such "Recursively Self-Improving Artificially Intelligent Systems" could defeat attempts to stop its progress by actively evading controls and by dynamically reprogramming itself. Providing human oversight to AI agents to enable it to safely assess and adjust its own internal codes and objectives is essential. This process is sometimes called "Artificial Intelligence Confinement" and many authors have described ways in which super-intelligent systems could use unexpected methods to beat human controllers, including co-opting humans through social media and by using newly acquired advanced powers of communication and persuasion to assist the AI system in escaping confinement.[19]

Our current expansion of biotechnology has created the new field of "synthetic biology" which has enabled synthetic organisms built with DNA created within computers and "bio-printed" into host organisms known as a "chassis." Synthetic biology enables humans to do remarkable things – such as massively produce any molecule of choice – be it a pharmaceutical or useful catalyst, to build bacteria that change color in the presence of trace elements, selectively absorb pollutants in an environment, or provide new ways to manufacture food using bioreactors instead of animals or traditional plants.

Synthetic Biology is able to alter the DNA within existing organisms to allow them to do useful work in creating specific chemicals or responding to the environment by absorbing chemicals or changing their state to enable sensing tasks. Since cells are able to reproduce easily on their own and very cheaply, the cells are instantly scalable for producing large amounts of nearly any desirable quantity – proteins, macromolecules, fuels or foods. Such modified organisms have been called "Genetically Engineered Machines" and an international competition known as the iGEM competition enables thousands of students to compete using such customizable organisms. The first iGEM competition in 2004 had only five schools and handfuls of students but by 2014, nearly 300 teams from 34 countries competed. In 2019, iGEM featured 353 teams from 409 different countries and reached 40,000 students.[20]

By using the complex machinery of bacteria, yeast and other organisms, synthetic biology is able to do extremely difficult chemical syntheses using very little energy. Because the "factories" are small and easily managed, the environmental impacts are greatly reduced and produce fewer toxic wastes than large scale industrial factories. The modern synthetic biologist is an expert at reading

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[18] Rogers, A., "The Way the World Ends: Not with a Bang But a Paperclip," Wired Magazine, Oct. 21, 2017, available at https://www.wired.com/story/the-way-the-world-ends-not-with-a-bang-but-a-paperclip/, accessed Jan. 9, 2020.
[19] Yampolskiy, R., 2016, *Artificial Superintelligence: A Futuristic Approach,* Taylor and Francis:Boca Raton.
[20] iGEM Competition, 2019, "iGEM's History," available at https://igem.org/About, accessed Jan. 9, 2020.

DNA, copying useful DNA sequences, and inserting those strands into host organisms for useful purposes. The techniques have been developed from decades of biology research that have produced technologies such as the Polymerase Chain Reaction (PCR) for copying DNA, gene sequencers for reading DNA, and new methods for inserting DNA such as rDNA. The result is an "abstraction" of the biological systems that has enabled specialists to focus on the process of harnessing molecular machinery within lifeforms for useful purposes. This practice has developed into a new discipline in its own right that makes use of biological advances and modern supercomputers to quickly read and write the four nucleotides of DNA to design interchangeable parts with ease. Much as mechanical engineers are able to build and exchange components such as gears and pulleys that are used within machines made from steel and glass, synthetic biologists can exchange sequences and organisms with ease and build upon existing stocks of biological machines. This form of standardization of bio-parts has enabled a proliferation of new synthetic biologists, and has greatly reduced the cost and difficulty of entering the field – much as the development of interchangeable parts enabled the expansion of the First Industrial Revolution.[21]

The new Biotechnologies, including Synthetic Biology, offer not only exciting new possibilities for enhancing our economy and creating new industries, but also offer the opportunity to help save our planet from otherwise daunting challenges in the coming century. Several authors have noted that this emerging 'bio economy' can provide more sustainable fuels and chemical production.[22] Since our planet will need 50% more food will be needed by 2050, within a context of degraded capacity from soil degradation and global climate change, FIR biotechnologies will be a crucial part of the solution to future agriculture. New bio-refineries for food and drug production could make use of cellulose, biomass, and simple sugars to produce a diverse range of food and pharmaceutical products in extremely large quantities. These technologies will enable us to shift away from fossil fuels in the coming decades and will have a much lower carbon footprint that our existing agriculture and industry. Synthetic organisms could also be used for environmental mitigation by removing various compounds from the environment such as toxic metals within landfills and can be designed to help in absorbing CO_2 and other greenhouse gases.

It is a wonderful thought to imagine this Fourth Industrial Revolution providing a technological solution to the environmental threats arising from the buildup of CO_2 and other greenhouse gases from the massive factories developed in our earlier Industrial Revolutions. New manufacturing processes will also be enabled by another of the FIR technologies known as the Internet of Things or IoT. The IoT allows nearly anything to be designed on a computer and then "printed" on 3D printers that create objects in nearly any material, even including "bioprinting" tissues and organs for medical use. This new IoT capability will the FIR industry to effortlessly turn "data into things and things into data." New types of 3D printers can be used to construct entire buildings and to move clumps of atoms and molecules only a few nanometers across.[23]

[21] Kuldell, N., Bernstein, R., Ingram, K., and Hart, K.M., 2015, *Biobuilder: Synthetic Biology in the La*b, O'Reily:Sebastopol.
[22] Philp, J. 2017. "The bioeconomy, the challenge of the century for policymakers ." *New Biotechnology*, Vol. 40, 11-19.
[23] Gershenfeld, N. 2012. "How to Make Almost Anything," *Foreign Affairs* 91 (6): 43-57.

Planning for the Future Economy and Higher Education within the FIR

As seen from the previous survey of history and emerging technologies, the evolution of technology and its impacts can give us a blueprint for a future FIR economic strategy and curriculum. The UAE Government, making note of this important principle, has launched the UAE Strategy for the Fourth Industrial Revolution,[24] which provides an inventory of many of these technologies of most importance in the future UAE economy. The specific elements of this strategy are listed below:

- "Innovative education will provide a smart and enhanced learning experience to develop advanced technologies such as science, nanotechnology and artificial intelligence.
- The adoption of intelligent and personal genomic medicine will lead to personalised medical technologies, improved health care levels and boost the UAE's position as a global centre for healthcare.
- The adoption of robotic healthcare and research in nanotechnology will facilitate the application of telemedicine and introduce cutting-edge medical solutions such as wearable and implantable technologies.
- achieve future security of water and food supply by using bioengineering sciences and advanced renewable energy technologies
- enhance economic security by adopting digital economy and blockchain technologies in financial transactions and service
- optimise the utilisation of satellite data in planning future cities
- develop advanced defence industries by developing national industries in the field of robotics and autonomous vehicle technologies."
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(from the UAE Strategy for the Fourth Industrial Revolution).

With this strategy, the UAE can position itself for the coming century, by creating more efficient and sustainable cities using artificial intelligence and IoT technologies. Robotics and genomics can combine within the new healthcare sectors enabling UAE and other modern countries to provide more reliable personalized medicines. Advancing quickly in these technologies will give a competitive advantage for a new medical industry which can become a major part of the future economy for UAE and other countries using these techniques. The emphasis within the strategy on using technologies to achieve greater water and food security is not unique to UAE, as global climate change will challenge all of the planet in these areas. This makes the project not only useful for sustaining UAE's future but for providing technologies transferable to the many other countries needing more advanced technologies for food production and water purification. As companies like SpaceX develop cheaper re-usable rockets, and smaller "cubesats" proliferate for remote sensing, a new economy of private space companies is emerging. Small satellites, sometimes just 10cm on a side, can provide increasing functionality at reduced cost, giving a number of opportunities in space that are useful for urban planning, monitoring environmental conditions and

[24] UAE Government, 2019, "UAE Strategy for the Fourth Industrial Revolution," available at https://government.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/the-uae-strategy-for-the-fourth-industrial-revolution, accessed Jan. 9, 2020.

for helping advance STEM capacity within the country. These are worthy goals and provide an excellent strategy for economic development in the coming century.

The UAE FIR strategy also includes the strategic area of Future Talent. In the UAE strategy, the need for preparing a national talent pool for FIR technologies who are entrepreneurial and also skilled in advanced subjects of science and technology is crucial. Developing student skills in the new FIR technologies need to be central in a student's education since these technologies will shape the future those students will live in, and students trained in this way will be able to develop amazing new materials, gene therapies, synthetic organisms, and brilliant computers, and completely reshape our economy.

Higher education generally tends to be one of "curation" in which the lessons of the past need to be transmitted to future generations. Academic institutions by their nature are conservative, and respect academic traditions, often with the best motivations for assuring excellence and transmitting the most valuable lessons from the past. However, with the future looking very different from the past, educational institutions of the future will need to modify their curriculum to enable the lessons from past knowledge to guide and inform the wise development of these revolutionary future 4IR technologies. This sort of revolutionary new curriculum will be one important outcome of the FIR - just as the earlier revolutions created much of our contemporary university curriculum.

This new kind of FIR curriculum will need to include substantial components of humanities and social sciences, which provide timeless lessons to students about the human condition. Our future curriculum will need to build on the lessons from the best liberal arts curricula, which provide courses to impart wisdom to students from their own cultural traditions as well as from global cultures, along with courses that help students gain a deeper understanding of the universality of the human condition across time and space. These lessons, which are found outside of the STEM fields, allow students to develop not only technical capacities but wisdom.

Social sciences will be vital for a future FIR curriculum to enable students to deeply understand theories of the mind and social groups, the cultural context of our experiences, and the methods which guide our creation of meaning. However since all of these terms are rapidly changing in our current era of massive online and social media presence, students will need to develop a capacity to understand the meaning of mind in the presence of AI technology, the meaning of social groups and culture within an online and global context, and the ways that society construct meaning in the presence of exponential technological advances. The study of Humanities is also vital to enable deep insight into the inner experiences of others, and to develop a capacity to define what it means to be human and live a good life, independent of the century and country one lives in. These lessons also are challenged by FIR technologies, as the boundaries between human and non-human, natural and artificial and notions of citizenship and ethics are all transformed with the rise of newly developed synthetic organisms, bio-printed organs, and globally linked cities and devices.

Ironically, answering these "enduring questions" which come from the social sciences and humanities will be even more important as accelerating technologies extreme ethical challenges and require thoughtful limits in the growth and deployment of these FIR technologies. The same technologies that have the potential to turbocharge our economic growth, extend human life, and fuel future industries have the potential to destroy ecosystems and undermine biodiversity, alter human genomics irreversibly, and supplant human intelligence with new AI systems that could leave millions unemployed. Precisely because the 4IR technologies accelerate – and generate advances exponentially – there is less of the luxury that we have had in past industrial revolutions to gradually adapt and shape our responses to technology through educational reforms decades later. We need not only to equip students with skills to develop these technologies sustainably and ethically. We need to develop higher education to allow students to develop the capacity for wisdom and to impart that wisdom into their AI algorithms, into their plans for artificial organisms, and into other technologies so they can enhance our future. It will discuss how the 4IR technologies will profoundly challenge our human condition, making a mandate for our response to be more than technological.

A new curriculum in FIR science will also be needed to help students more efficiently develop skills and knowledge about cutting-edge topics in science and technology earlier in their education. New science curriculum needs to be designed focusing directly on the rapidly emerging areas of genomics, data science, artificial intelligence, robotics and nanomaterials. Such a FIR STEM curriculum should re-center the curriculum outside or between the traditional "primary" disciplines of biology, chemistry and physics, and will need to place a higher premium on computer science subjects as a form of FIR literacy. Within biology, introductory courses should incorporate synthetic biology and molecular design in the first year of instruction. Examples of such a 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,[25] 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.

At my own institution, Soka University of America, we have designed a new interdisciplinary Life Sciences curriculum that places students into authentic research problems in their first year that makes use of genetically engineered organisms, and uses case studies of research topics in the first-year introductory courses. New FIR Physical Sciences curriculum will need to be developed to emphasize quantum computing, materials science and IoT technologies, and to develop sophisticated collaborative skills to allow students to develop devices within diverse teams of students. Some notable present-day Physics courses provide examples of 4IR Physical science. These include an introductory physics course at Harvard, where students design and build original musical instruments, cryptographic gadgets, and other inventions collaboratively.[26] Other modern introductory physics courses have been developed to provide deep knowledge of quantum mechanics within the first semester, to enable students to develop facility with quantum computing, nanomaterials and other advanced technologies earlier in their careers.[27] In chemistry, the new Green Chemistry movement has created both research and education in synthesizing new chemicals with fewer environmental impacts and can be made a central part of new types of

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[25] Cyert, M. 2017. *Developing a New Introductory Biology Curriculum.* Accessed November 2, 2017. **https://vptl.stanford.edu/spotlight/developing-new-introductory-biology-curriculum**.
[26] Perry, C. 2013. *In Ap 50, Students Own their Education.* September 23. Accessed December 2, 2017. https://www.seas.harvard.edu/news/2013/09/in-ap-50-students-own-their-education.
[27] Moore, T., 2019, *Six Ideas That Shaped Physics*, project website at http://www.physics.pomona.edu/sixideas/, accessed Jan., 9, 2020.

Chemistry education. These principles include ideas such as preventing chemical waste, "atom economy," developing less hazardous chemical syntheses, designing safer chemicals and solvents, working for greater energy efficiency and more renewable "feedstocks," real-time analysis for pollution prevention, and new methods of catalysis, among other ideas.[28]

Conclusion – Key Lessons from the Fourth Industrial Revolution

As described in the previous sections, each of the FIR technologies requires a realignment of our STEM disciplines and curriculum to enable students to navigate and contribute to these areas quickly and effectively. Perhaps more importantly, these FIR technologies also include a rich wealth of connections to disciplines far outside of STEM fields. Such connections to the humanities and social sciences will need to be developed within FIR education alongside of more advanced STEM topics to enable students to wisely and ethically shape the future century we all will live in. Each of the FIR technologies contains a nucleus of new ideas that will either destabilize our civilization and planet or assure our launch of entirely new and more sustainable industries that will help us assure our long-term survival as a species. A recipe for higher education in the future would be to create a university that is re-centered on these emerging technologies, and that trains students in advanced capacity for developing these technologies, and then harnesses them to purposes that will advance the sustainability of the planet.

One model for a new FIR education would be based on a FIR STEM curriculum where students work directly on projects, courses, and even majors that use FIR technologies on solutions that align with the UN Sustainable Development Goals. The UN in 2015 issued a report entitled "Transforming our World: the 2030 Agenda for Sustainable Development" that includes "17 Sustainable Development Goals with 169 associated targets which are integrated and indivisible."[29] These 17 goals are listed below, which provide a target for FIR technologies beyond economic growth:

> The UN Sustainable Development Goals (from "Transforming our world: the 2030 Agenda for Sustainable Development"):
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> - Goal 1. End poverty in all its forms everywhere
> - Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
> - Goal 3. Ensure healthy lives and promote well-being for all at all ages
> - Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
> - Goal 5. Achieve gender equality and empower all women and girls

[28] American Chemical Society, 2019, "12 Principles of Green Chemistry," https://www.acs.org/content/acs/en/greenchemistry/principles.html, accessed Jan. 9, 2020.

[29] U.N., 2015, "Transforming our world: the 2030 Agenda for Sustainable Development," Available at https://sustainabledevelopment.un.org/post2015/transformingourworld, accessed Jan. 9, 2020.

- Goal 6. Ensure availability and sustainable management of water and sanitation for all
- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- Goal 10. Reduce inequality within and among countries
- Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
- Goal 12. Ensure sustainable consumption and production patterns
- Goal 13. Take urgent action to combat climate change and its impacts*
- Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
- Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

Over half of the 17 goals can be approached using more innovative and widespread use of new FIR technologies. These especially include goals 2,3,6, and 7 which require more efficient food production, advances in biomedicine, new methods for providing clean water, and new sources of energy, which all are likely to be possible with biotechnologies and new materials developed during the FIR. Some of the goals affect regions of larger spatial scale at the size of cities or even planetary scale such as 9, 11, 13, 14, and 15, and similarly can be addressed through new technologies. More resilient infrastructure using IoT technology, new "smart cities," mitigating global climate change with new materials and biotechnology, improved monitoring and cleanup of the oceans and ecosystems using space technologies and robotic platforms will all advance these particular U.N. Goals.

As a perfect example of the convergence FIR technologies deployed for helping green the planet, managing forests and reducing global climate change, a UK company named *Dendra* plans to plant 500 billion trees by 2060 – using AI and drones. The company states that its drones can plant 120 seedpods per minute – and with AI technologies can do so largely unattended, allowing a fleet of drones to "re-green the planet."[30] And while over half of these SDG's can be largely addressed with technology, many of the remaining goals can be developed through improved access to education, and through more advanced social science models and datasets. The advances in social sciences, which while not directly a FIR technology, will be made much easier with new networked

[30] World Economic Forum, 2019, "This tech company is aiming to plant 500 billion trees by 2060 – using drones," https://www.weforum.org/agenda/2019/12/technology-artificial-intelligence-ai-drone-trees-deforestation/, accessed Jan. 9, 2020.

platforms making use of global communities of citizen researchers and more advanced AI-powered software.

It is also important to also note that within the FIR technologies are deeper meanings that will transform our cognitive awareness of the world and how it works in the coming century. Entirely new cognitive frameworks in courses are sometimes labelled as “threshold concepts.” A threshold concept is a qualitatively new ideas which requires a change in thinking before a student can continue onwards into more advanced topics. The threshold concept often can be described as “troublesome knowledge” which requires a new way of looking at the world, but once understood induces a transformative form of learning. Meyer et al. described threshold concepts as those that require an “ontological shift” and that produce transformative and irreversible learning, creating an awareness of the interrelatedness of many phenomena, often arising from key points where a discipline has had to undergo a paradigm shift[31].

The FIR “threshold concepts” will similarly require all of us too undergo a paradigm shift as we develop deeper understanding of the larger meanings and implications of the FIR science and technology for our society. One of the richest of these FIR “threshold concepts” comes from the concept of Quantum Entanglement (which comes from development of quantum computing). Entanglement is something of a metaphor for this era as it describes both the indeterminacy and complexity that arises from not collapsing a quantum wave function but instead from allowing two particles to “mix” in their probability wave states. As such, the notion of “entanglement” mirrors a 21st century mindset, which often requires the suspension of judgement and the need for cognitive complexity as we work within diverse populations to decipher the meanings that arise from this new era. Understanding the complexity of our entangled human identities as a global community will help us develop a new FIR notion of “global citizenship” that includes not the single waveforms of one’s individual upbringing, but also the superpositions of additional “intersectional” identities that arise from our interactions with others in dynamic global cities such as Dubai and Abu Dhabi.

The FIR technology of Artificial Intelligence also brings us a deeper insight into the nature of mind and thought. Imbedded in the FIR AI technology is the need for a distinction between intelligence and wisdom - and the urgent requirement for regulations to limit artificial intelligence and contain it for ethical uses. With the advances in Biotechnology and Synthetic Biology, we will create the potential for engineering life in a way that redefines our relationship with nature and challenges what it means natural or artificial. Pairing these technologies with art, writing, communication and humanities will help us capture better capture the essence our changing relationship with Nature.

In addition to conceptual and curricular challenges, the FIR will also require us to reconsider the temporality of higher education. Since the “shelf life” of any skill in the present-day environment has become increasingly short, future workers will need to be continuously trained to have the capacity to update their skills and teach themselves about new technologies and even entire industries that may not have existed while they were being trained for their initial degrees. New

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[31] Meyer, J.H.F., Land, R. and Davies, P., 2006, “Implications of threshold concepts for course design and evaluation,” in Meyer, J.H.F. and Land, R. (eds.), *Overcoming Barriers to Student Understanding: threshold concepts and troublesome knowledge*, London and New York: Routledge.

methods to extend their education beyond the initial four years and to refresh their ideas and skills (and share them with younger students) can revitalize universities and help both faculty and students remain current in their knowledge. As we add in new methods for including students and recent graduates into our higher education, new methods for structuring and signaling education beyond a college transcript will also be required. Some ideas for this have been proposed within the Stanford 20205 project, such as an "open loop university" which opens up higher education to beyond the four-year undergraduate experience, enabling a series of journeys in and out of the academy to provide lifelong learning. The project also identified more use of adaptive learning as a potential frontier to make learning more personal and suited to the individualized pace of a student. "Flipping the axes" was proposed to prioritize skill development over content knowledge in courses and help students learn faster and improve the efficiency of courses. Finally, the Stanford 2025 project envisioned new types of credentials beyond the standard college transcript that can adapt with a student's life after graduation.[32]

More recently a second volume of the Stanford2025 report was written to research how existing universities were already implementing some of the ideas mentioned in the earlier report. The new volume provides case studies of a dozen new and innovating universities, giving good insights into new models of curriculum and education that may be useful in the future. Some of the institutions profiled include the African Leadership Universities, which are located in a variety of cities and countries in Africa, offering an interdisciplinary degree in Global Challenges, and employing new types of pedagogy including increased use of hybrid instruction and an emphasis on networked peer mentoring. The study also profiles Duke Kunshan University in China, which is developing new models of liberal arts in China with "rooted globalism" at its core and interdisciplinary courses with a novel academic calendar, Minerva University, which has attempted to use a new online platform with a small group of students living together in a variety of world cities to attempt to provide a reduced cost for residential education, among others.[33] These new universities are all developing interesting new models for the future of higher education which can help inform our planning for not only new types of curriculum but also are demonstrating new academic calendars and entirely new modes of instruction.

In all of our discussions about technology and change, it is important to remember that we as human beings retain the same marvelous cognitive and emotional complexity as in previous centuries, and that the human condition will always retain its same essential features. Despite the development of advanced computers, our brain is still the most powerful computer known on earth. One cubic mm of the human brain contains as many computational possibilities as all the grains of sand in the earth. While this potential is vast, we routinely only tap 10% or less of the brains full computational power. Bringing more effective forms of education will allow us to use all of our potential for thought and development and bring us a better future. Education for the Fourth Industrial Revolution requires us to initiate bold new courses and institutions to advance STEM education. It will also require us 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. Such a curriculum will ensure that our students will

[32] Stanford2025. 2013. *Learning and Living at Stanford - An Exploration of Undergraduate Experiences in the Future.* June 1. Accessed December 3, 2019. http://www.stanford2025.com/.

[33] Stanford2025, 2019, *Stanford2025 – Volume 2 - Uncharted Territory*, available at https://dschool.stanford.edu/unchartedterritory.

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.