CHAPTER 9

The Fourth Industrial Revolution and Higher Education

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The Fourth Industrial Revolution (4IR) is a concept widely discussed at venues such as the World Economic Forum (WEF) at Davos and within business leadership. Recent white papers describe how the 4IR will "shape the future of education, gender and work"[1] and how the 4IR will require "accelerating workforce reskilling."[2] A full exposition of the schema and framework of the 4IR has been presented in book form with an inventory of some of the key emerging technologies that are thought to drive the 4IR and some societal implications from the 4IR.[3] The 4IR as a phrase has its

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[1] World Economic Forum, "Realizing Human Potential in the Fourth Industrial Revolution – An Agenda for Leaders to Shape the Future of Education, Gender and Work" (paper, World Economic Forum, Geneva, 2017).

[2] World Economic Forum, "Accelerating Workforce Reskilling for the Fourth Industrial Revolution An Agenda for Leaders to Shape the Future of Education, Gender and Work" (paper, World Economic Forum, Geneva, 2017).

[3] Klaus Schwab, "The Fourth Industrial Revolution: what it means, how to respond," January 14, 2016, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

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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 mention steam engines applied to the mining in Cornwall and the role of steam power in enabling massive increases in the scale of manufacturing. Steam power has been eloquently described as "the hub through which the spokes of coal, iron and cotton were linked."[4] The origin of the term industrial revolution itself traces to an 1884 work by Arnold Toynbee entitled *Lectures on the Industrial Revolution*.[5] Within Toynbee's description of the industrial revolution, the expansion of power and mechanical production became a revolution only from its coupling with a "political culture which was receptive to change,"[6] which included shifts in financial arrangements as well as other social progress. As one author put 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."[7] Social and educational transformations from the first three industrial revolutions can provide a starting point in our consideration of the potential transformations in higher education arising from the 4IR.

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 degree options and new general education programs designed to produce breadth of study through the selection from a variety of elective courses. This type of education was described by the Harvard President Charles W. Eliot as "The New Education"[8] and offered a dramatic shift away from the dominant classical education eloquently outlined in the Yale Report of 1828.[9] University graduate

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[4] William Rosen, *The Most Powerful Idea in the World – A Story of Steam, Industry and Invention* (Chicago: University of Chicago Press, 2010).

[5] Toynbee, *Lectures on the Industrial Revolution* (London: Rivingtons, 1884).

[6] Gavin Weightman, *The Industrial Revolutionaries* (New York: Grove Press, 2007), 3.

[7] Eric Hobsbawm, *Industry and Empire – The Birth of the Industrial Revolution* (New York: The New Press, 1968).

[8] Charles L. Eliot, "The New Education," *The Atlantic Monthly* XXIII, (1869).

[9] Yale University, *Reports on the Course of Instruction in Yale College: by a Committee of the Corporation and the Academical Faculty* (New Haven: Hezekiah Howe, 1828).

education within the United States and across the world was transformed by 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 to 1900, and is associated with new manufacturing technologies based on electricity,[10] which triggered additional changes launching what some have described as a "new economy."[11] An expansion of access to higher education and the proliferation of multiple types of higher education institutions in the United States and Europe produced 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"[12] and to enable higher education that is "accessible to all, but especially to the sons of toil."[13] 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"[14] such as agriculture and the mechanic arts. Private philanthropy, fueled by the immense profits from new industries such as railroads, oil and steel, enabled the founding of institutions such as Stanford University (1885) and 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

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[10] Bruce C. Netschert and Sam H. Schurr, *Energy in the American Economy, 1850–1975: An Economic Study of its History and Prospects* (Baltimore: Johns Hopkins University Press, 1960).

[11] Andrew Atkeson and Patrick Kehoe, "Modeling the Transition to a New Economy: Lessons from Two Technological Revolutions," *American Economic Review* 97, no. 1 (2007): 64–88.

[12] Quoted in "The Morrill Act of 1862," University of Nebraska-Lincoln, accessed January 10, 2018, https://sdn.unl.edu/morrill-act.

[13] Quoted in Peter McPherson, "Celebrating the 125th anniversary of the Morrill Act of 1890," Association of Public Land-Grant Universities, July 15, 2015, http://www.aplu.org/news-and-media/blog/celebrating-the-125th-anniversary-of-the-morrill-act-of-1890.

[14] Roger L. Geiger, *The Land-Grant Colleges and the Reshaping of American Higher Education* (New York: Routledge, 2017), x.

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 responded to the societal and economic changes rapidly building in the end of the nineteenth 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 of the period that included 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.[15] Spectral analysis of world GDP growth has identified peaks in annual average GDP growth in the period of 1850–1875 and 1895–1913,[16] 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 adapted 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.[17] The results suggest that historically, changes within society and the impacts of technology on education require 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 catalyzing technologies of steam and electricity.

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[15] Nikolai. D. Kondratieff and W. F. Stolper, "The Long Waves in Economic Life," *Journal of Economic Statistics* 17, no. 6 (1935): 105–115.

[16] Andrey V. Korotayev and Sergey V. Tsirel, "A Spectral Analysis of World GDP Dynamics: Kondratieff Waves, Kuznets Swings, Juglar and Kitchin Cycles in Global Economic Development, and the 2008–2009 Economic Crisis," *Structure and Dynamics* 4, no. 1 (2010): 1–55.

[17] Atkeson and Kehoe, "Modeling the Transition to a New Economy."

The proliferation of new educational institutions and new curricula 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 twentieth 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,"[18] and 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 and 1966. In the development of its 3600 universities and colleges, the United States created a massive system which today 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.[19] 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 education industry 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 1980s and 1990s, 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

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[18] Vannevar Bush, "Science The Endless Frontier," July 1, 1945, https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm.

[19] Vartan Gregorian, "American Higher Education: An Obligation to the Future," *Carnegie Reporter*, 2014. https://higheredreporter.carnegie.org/introduction/.

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 participation in higher education in India, China as well as the United States. For example, in the United States the fraction of the population with some access to higher education has risen from 4% in 1900 to nearly 70% in 2000. The increasing diversity within student populations is also remarkable, with a 30% rise in enrollments in underrepresented groups, resulting in 38% 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 were expected 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 more likely to result in an integration of high quality, synchronous, in-person learning environments with 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.[20] Within the environment of increasing online content delivery and access to information, these more personal and "high-touch" 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 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 with new types of technologies that improve on-campus experience for students through online math courses for incoming students, language

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[20] Michael Staton, "Disaggregating the Components of a College Degree," August 2, 2012, http://www.aei.org/wp-content/uploads/2012/08/-disaggregating-the-components-of-a-college-degree_184521175818.pdf.

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 (LACOL), which has brought together some of the leading US liberal arts colleges to explore these technologies.[21] 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 are developing dozens of new "stackable micro-credentials"[22] that link multiple online courses with in-person consultations with faculty and opportunities for students to conduct significant original capstone projects.

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.[23] 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,[24] Liberal Studies in Engineering,[25] the American Physical Society SPIN-UP project[26] and the HHMI Scientific Foundations for Future Physician report.[27] All emphasize more interdisciplinary approaches in STEM that develop student capacity for collaboration and social interaction within STEM courses and curriculum.

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[21] LACOL, "Liberal Arts Consortium for Online Learning," July 1, 2017, http://lacol.net/.

[22] Jeffery R. Young, "The New Frontier in Online Education," *Slate*, October 10, 2017, http://www.slate.com/articles/technology/future_tense/2017/10/microcedentials_are_the_new_frontier_in_online_education.html.

[23] Eris Mazur, "Farewell, Lecture?," *Science* 323, no. 5910 (2009): 50–51.

[24] Susan Elrod and Arianna J. Kezar, Increasing Student Success in STEM: A Guide to Systemic Institutional Change (Washington, D.C.: AAC&U, 2016).

[25] Louis Bucciarelli and David Drew, "Liberal Studies in engineering – a design plan," *Engineering Studies* 7, no. 2–3 (2015): 103–122.

[26] Robert C. Hilborn, Ruth H. Howes, and Kenneth S. Krane, eds., *Strategic Programs for Innovations in Undergraduate Physics* (College Park: The American Association of Physics Teachers, 2003).

[27] AAMC, *Scientific Foundations for Future Physicians* (Washington, D.C.: Association of American Medical Colleges, 2009).

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 between students within a residential community. One example is Yale-NUS College in Singapore, developed by Yale University and the National University of Singapore to provide a residential liberal arts college within Asia. Yale-NUS College offers an interdisciplinary curriculum which features literature and philosophy from both Eastern and Western cultures, a range of interdisciplinary science courses and quantitative reasoning, and courses in Modern Social Thought and Comparative Social Inquiry 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 twenty-first century.[28] 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 how these questions are answered in a social context, drawing from classic works of Chinese, Indian and Greek philosophers, European social theorists and modern interpretations of twenty-first-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, dialogue and reflection within an international context.[29] A third curriculum being developed by Duke University for its new Duke-Kunshan University in China explores the concept of "rooted globalism," and blends an appreciation for a local culture with an exploration of international approaches to identity and society, and develops a framework for liberal arts in China in the twenty-first century.[30]

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[28] Bryan Penprase and Terry Nardin, "Common Curriculum at Yale-NUS," July 1, 2017, https://indd.adobe.com/view/b8748bf2-c7a6-4cef-a1e6-9a30c36bfe80.

[29] Soka University of America, "General Education Curriculum," Accessed December 3, 2017, http://www.soka.edu/academics/general-education-curriculum/default.aspx.

[30] Kara A. Godwin and Noah Pickus, "Liberal Arts & Sciences Innovation in China: Six Recommendations to Shape the Future," *CIHE Perspectives*, November 1, 2017. https://www.bc.edu/content/dam/files/research_sites/cihe/pubs/CIHE%20Perspective/CIHE%20Perspectives%208_ENGLISH_13NOV2017.pdf.

Emerging Realities from the 4IR

The 4IR often is described as the result of an integration and compounding effects of multiple "exponential technologies," such as artificial intelligence (AI), biotechnologies and nanomaterials. One example of the emerging reality within the 4IR is the development of synthetic organisms (life from DNA created within computers and bioprinted) manufactured using robotic assembly lines, where nanomaterials provide immense improvements in the efficiency of production. The 4IR 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 labor forces within large corporations—will no longer exist. The most familiar exponential technology is the exponential increase in computer power and decreasing 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,[31] 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 AI—the combination of multiple exponentially developing technologies compounds and multiplies 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.[32]

The WEF has defined a set of tipping points at which the technologies of the 4IR will become widespread enough to create massive societal change. These tipping points include the proliferation of 4IR 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

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[31] Michael A. Peters, "Technological Unemployment: Educating for the Fourth Industrial Revolution," *Journal of Self-Governance and Management Economics* 5, no. 1 (2017): 25–33.

[32] Ray Kurzweil, *The Singularity is Near* (New York: Penguin, 2005).

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, and driverless cars comprising 10% of all cars in the United States by 2026. Many other predictions suggest extensive integration of AI in the 4IR workforce, such as AI members of corporate boards of directors, AI auditors and robotic pharmacists, proliferation of bitcoin in the economy, 3D printed cars by 2022, and transplants of 3D printed organs such as livers by 2024.[33]

One author has described the 4IR as a shift from non-renewable energy resources toward renewable energy enabled by biotechnology breakthroughs. This approach preserves the paradigm of the industrial revolution arising from new energy sources, and makes concrete predictions about the emerging bioeconomy that will fuel the future.[34] Increasing population and losses of arable land due to global climate change will require an increase in food production efficiency of over 50% by 2050, which places an imperative on 4IR technologies developing revolutionary new sources of food production. The emergence of biorefineries 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 4IR landscape. These biorefineries 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 in 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.”[35]

The 4IR may also enable technological solutions 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

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[33] World Economic Forum, *Deep Shift – Technology Tipping Points and Societal Impacts* (Geneva: World Economic Forum, 2015).

[34] James Philp, “The bioeconomy, the challenge of the century for policy makers,” *New Biotechnology* 40, part. A (2018): 11–19. https://doi.org/10.1016/j.nbt.2017.04.004.

[35] D. E. Cameron, Caleb Bashor, and James Collins, “A brief history of synthetic biology,” *Nature Reviews Microbiology* 12, (2014): 381–390.

uninhabitable through an increase of more than 10 °C, which would result in widespread crop failures and large fractions of the world's populations subject to heat exhaustion and potential death. The predicted increases in temperature will significantly reduce agricultural productivity by as much as 15% for every degree of warming.[36] New technologies could mitigate global warming by absorbing excess CO_2 using both bioengineered organisms and new materials within buildings.

In the new manufacturing regime enabled by 4IR technologies, sometimes called the Internet of Things (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. 3D printing materials could range from the familiar thermoplastics found in traditional 3D printers to large-scale construction materials for buildings, to clumps of atoms 10 nm across.[37] This expansive IoT capability will enable printers to construct entire buildings, build microstructures with incredibly precise tolerances, or create biological structures for implants or even transplants of entire organs.

Higher Education's Response to the 4IR

The exact impacts of such 4IR 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 4IR 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 AI agents with increasing autonomy within financial sectors and within urban infrastructure.

Substantial changes to the science and technology curriculum will be required to allow for students to develop capacity in the rapidly emerging areas of genomics, data science, AI, robotics and nanomaterials. Such a 4IR STEM curriculum would reconsider the curriculum within the traditional "primary" sciences—biology, chemistry and physics—and

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[36] David Wallace-Wells, "The Uninhabitable Earth," *New Yorker*, July 9, 2017, http://nymag.com/daily/intelligencer/2017/07/climate-change-earth-too-hot-for-humans.html.

[37] Neil Gershenfeld, "How to Make Almost Anything," *Foreign Affairs* 91, no. 6 (2012): 43–57.

place a higher premium for training in computer science subjects as a form of 4IR 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 experiments to develop cures to real-world pathogens such as Lyme disease and HIV, using authentic data from scientific literature,[38] or a new course in engineering biology that allows students to design their own life forms on computers and bioprint them to solve practical problems in medicine, public health and environmental management. These courses are a response to the emerging bioeconomy, which already exceeds $400 billion in the United States alone.[39] Within the Stanford curriculum is a new major known as bioengineering, which trains students at the "interface of life sciences and engineering"[40] and merges expertise and resources in the departments of medicine, biology and engineering. 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 and toxicology, and to train students in techniques to reduce pollution.[41] New physics curriculum emphasizing 4IR collaborative skills is also being developed, based on projects where students design and build original musical instruments, cryptographic gadgets and other inventions collaboratively.[42] Additional educational responses to 4IR might require a restructuring of institutions to provide new science programs and departments in emerging interdisciplinary fields to more efficiently provide trained workers to help advance

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[38] Martha Cyert, "Developing a New Introductory Biology Curriculum," Accessed November 2, 2017, https://vptl.stanford.edu/spotlight/developing-new-introductory-biology-curriculum.

[39] Drew Endy, "Yale-NUS College STEM Innovation Conference," April 27, 2016, http://steminnovation.sg/wp-content/uploads/2017/06/Endy_Yale_NUS_STEM_v1.pdf.

[40] Tom Abate, "New Bioengineering Major culminated department's evolution," October 22, 2015, https://engineering.stanford.edu/news/new-bioengineering-major-culminated-department-s-evolution.

[41] Liliana Mammino and Vânia G. Zunin, *Worldwide Trends in Green Chemistry Education* (Cambridge: Royal Society of Chemistry, 2015).

[42] Caroline Perry, "In Ap 50, Students Own their Education," September 23, 2013, https://www.seas.harvard.edu/news/2013/09/in-ap-50-students-own-their-education.

and accelerate the development of ever-more sophisticated biotechnology, nanotechnology materials and AI.

Any educational plan for the 4IR must be built upon the results of the Third Industrial Revolution described earlier, 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 flipped and online courses will make more efficient learning environments that can adapt for diversity in preparation of 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.[43] Examples of effective blended environments include the supremely popular CS 50 course at Harvard,[44] 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.[45]

Any effective 4IR education strategy must also include in equal measure a deep consideration of the human condition, the ways in which new technologies and shifting economic power impact people of all socioeconomic levels, and the threats that exist within a world that is increasingly interconnected, in a way that fosters deep intercultural understanding and an abiding respect for freedom and human rights. Such approaches favor an interdisciplinary and global curriculum in a residential context, such as is found in many liberal arts institutions. These approaches maximize the development of intercultural and interpersonal skills, which will be a hallmark of the future 4IR workplace.

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[43] MIT, "Institute-wide Task Force on the Future of MIT Education," July 1, 2013, https://future.mit.edu/.

[44] Cordelia F. Mendez, "This is CS50," *Fifteen Minutes Magazine*, September 18, 2014, http://www.thecrimson.com/article/2014/9/18/this-is-cs50/.

[45] Nick Roll, "For-Credit MOOC: Best of Both Worlds," June 15, 2017, https://www.insidehighered.com/news/2017/06/15/credit-mooc-proves-popular-among-mit-students.

4IR LIBERAL ARTS: AN ETHICAL IMPERATIVE FOR OUR NEW HUMAN CONDITION

More than anything, the 4IR 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 teach themselves about new technologies and new industries that may not have existed while they were being trained for their initial degrees. A further design requirement for education within 4IR 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 4IR form of higher education will ensure 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 4IR 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 and the increasing complexity and 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 4IR workplace.[46] Integration of 4IR technologies such as the IoT in both CTE and more academic settings requires a simultaneous treatment of rapidly changing technical details and building capacity for teamwork and collaboration within students.

The changing nature of work—which favors more flexible and shorter-term assignments—has been cited as a key factor to address within 4IR education. Future jobs within the 4IR technology sectors, AI, machine learning, robotics, nanotechnology, 3D printing, genetics and biotechnology, are expected to dominate in the coming decades. Within

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[46] Jay W. Rojewski and Roger B. Hill, "A Framework for 21st-Century Career-Technical and Workforce Education Curricula," *Peabody Journal of Education* 92, no. 2 (2017): 180–191.

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.[47] 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.[48]

Fourth Industrial Revolution Liberal Arts: New Elements to the Curriculum

The 4IR and its associated technologies such as biotechnology and AI 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 4IR Liberal Arts Program.

The social dislocations from the 4IR have to be accounted for within a new 4IR liberal arts curriculum. Already we have seen the correlation between corporate earnings, productivity gains and wage increases break down. As smart AI-powered machines and other advanced technologies become more common within corporations, this trend is only expected to accelerate. The 4IR curriculum needs to respond to the political and social tensions that will accompany the accelerating pace of technological change, and to respond to the paradox of technologies that simultaneously increase democratization and centralize wealth and political influence. As described in one of the WEF reports, the political effects of the 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 even circumvent the supervision of public authorities. Simultaneously, governments will gain new technological powers to increase their control over populations."[49]

With the evolution of online instruction and expanding uses of AI, new guidelines are needed to provide a theoretical basis for digital pedagogy. Some have called the old models of teaching "anthropocentric

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[47] World Economic Forum, *The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution* (Geneva: World Economic Forum, 2016). http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf.

[48] George Anders, *You Can Do Anything: The Surprising Power of a "Useless" Liberal Arts Education* (New York: Little, Brown and Company, 2017).

[49] Schwab, "The Fourth Industrial Revolution."

humanism" and the new types of digital education "critical posthumanism." These approaches stress that digital education is more than a purely technical concern, as online environments change the dynamics of space and time to create new learning cultures that challenge our earlier notions of social interactions and enable new perspectives on our shared humanity, independent of geographic boundaries.[50] Such a curriculum can also help students grapple with the complex issues of relationships within online spaces and the philosophical dimensions of AIs 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"[51] where divisions between nature and culture, public and private and human and non-human break down. These humanistic concerns are inseparable from technical advancement, and a new 4IR 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 4IR, including discussions of autonomy, free will, and genetic vs. social determinism. The changing nature of social relations and interactions—social media, obligations to identity groups, society, nation and world needs to be central in the 4IR curriculum as all of these identities and loyalties are shifting rapidly due to increased globalization.

More than ever, higher education in the 4IR age must develop the capacity not just for analyzing and breaking a technical or scientific problem into its constituent parts, but also must 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, "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."[52] 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

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[50] Petar Jandric, "From Anthropocentric Humanism to Critical Posthumanism in Digital Education," in *Learning in the Age of Digital Reason* (Rotterdam, Sense Publishers, 2017), 195–210.

[51] Donna Haraway, "A Cyborg Manifesto: Science, Technology, and Specialist-Feminism in the Late Twentieth Century," in *The Cybercultures Reader*, eds. David Bell and Barbara M. Kennedy, (London: Routledge, 2000), 291–324.

[52] Peters, "Technological Unemployment," 36–37.

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 4IR curriculum needs to train students to recognize and help manage the proliferating numbers of exponentially responding and interconnected 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 4IR will require rapid expansion of existing initiatives for updating skills after graduation and reconnecting within older workers in campus environments. Within scientific and technical education, we will need to educate and reeducate students to help develop and shape the use of today's most rapidly emerging technologies. Pathways for students to reengage 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.[53]

The hallmark of the 4IR is exponential growth and rapid change, which gives the curriculum an imperative to update 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 develop students who can think and reinvent themselves within the changing

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[53] Stanford2025, "Learning and Living at Stanford – An Exploration of Undergraduate Experiences in the Future," June 1, 2013, http://www.stanford2025.com/.

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 experts to frequently renew and update their skills. To enable faculty to maintain expertise based on the latest discoveries and technologies, more proactive and creative forms of faculty development will also be required.The 4IR campus must become a constantly renewing collaborative hub of activity to maintain itself within the fast-paced environment of the future.

Conclusion

The first three industrial revolutions provided evidence for the profound shifts in society, the economy and education which resulted in a proliferation of curricular innovation and the establishment of new educational institutions. As in the previous three industrial revolutions, the most profound effects of the 4IR on our society will not be realized for many decades. Unlike previous industrial revolutions, however, the 4IR 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 in earlier industrial revolutions.

The impacts of the emerging 4IR technology in economic and environmental terms alone will require a drastic reconsideration of the curriculum within higher education to enable students both to comprehend the individual technologies in detail and to be able to thoughtfully analyze and predict the evolution of networked systems of technology, the environment and sociopolitical systems. The dynamic responses with networked systems and exponential feedback effects will amplify the pace of change, as has already been seen in the context of global climate change and in many other physical and biological contexts. The 4IR STEM curriculum will need to focus on emerging technologies—robotics, AI, IoT, nanomaterials, genomics and biotech—to provide a workforce not only capable of developing new applications and products, but also 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 the capacity for ethical reasoning, for awareness of societal and human impacts, and to be able to comprehend the impacts of 4IR technologies on people, so they are trained to not only increase our material prosperity but also to improve 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 in physical resources such as land, water power, coal, oil and wood—the 4IR 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 will be well trained for the types of tasks that will be asked of them in the 4IR. 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." Many of the emerging liberal arts institutions in the United States and Asia and new types of CTE curricula are providing useful examples of how to implement this new model of 4IR higher education. Higher education needs to recognize the necessity of adapting and scaling up these new 4IR forms of education rapidly 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. Taken together, these new forms of 4IR 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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