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The Growth of Interdisciplinarity in Engineering Education in the 21st Century

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Abstract:

During the exploration and progression of knowledge from the fifteenth through eighteenth centuries, there was no established boundaries for disciplines, and scholars made simultaneous contributions in many knowledge domains. With the evolution of the first two industrial revolutions, a growth of specialization in engineering field of expertise began emerging in the nineteenth century. The second half of the twentieth century saw the rise of the silos in engineering due to the requirement of disciplinary specializations. Advanced technologies such as personal computers and internet served as a major catalyst in accelerated growth in depth and breadth of knowledge in respective engineering discipline during the third industrial revolution. With the advent of the fourth industrial revolution, we are beginning to study evolving phenomenon involving the breaking down the silos resulting in the emergence of interdisciplinarity across and beyond engineering fields.

From a pedagogical perspective, two distinct types of interdisciplinary approaches are identified: 1) Bolstering of existing fields with infusion of technological knowledge and 2) Evolution of hybrid fields combining two or more existing fields. Inclusion of emerging technologies in the era of Industry 4.0 such as artificial intelligence (AI), Internet-of-Things (IoT), and Robotics will also be discussed. Examples such as smart cities, smart manufacturing, and innovations in the medical & health sectors will be used to demonstrate pedagogical approaches. The engineering educational curriculum of the third decade of the 21st century is proposed to be as follows: 1) Creation of new curriculum incorporating hybrid education 2) Use of new teaching tools offering flexibility to students and 3) Proposing interdisciplinary within and across programs between different engineering disciplines.

Keywords: Industry 4.0, Hybrid Engineering Education, Interdisciplinarity, Pedagogical Approaches

The Growth of Interdisciplinarity in Engineering Education in the 21st Century

Introduction:

As knowledge evolved from the fifteenth through the eighteenth centuries, no established boundaries between subjects existed, and scholars made simultaneous contributions in many knowledge domains. For example, in the fifteenth century during the Italian Renaissance period, Leonardo Davinci was not only an engineer and a scientist, but also an architect, artist and anatomist [1]. Continuing in this region in the sixteenth century, Michelangelo also contributed to engineering fields such as architecture and to arts such as sculpture, painting and poetry as well [2]. Similarly, in the seventeenth century, Wenceslas Coebergher was from the Flemish Renaissance and was not only an architect and an engineer, but also a painter, antiquarian, numismatist, and an economist. Such examples can also be found in the eighteenth and nineteenth centuries. Finally, in the eighteenth century, Benjamin Franklin is perhaps best known as the one of the founding fathers of the United States, but also well known for his engineering innovations and scientific inventions; simultaneously he was also a leading writer, printer, philosopher, postmaster, civic activist, and much more [3].

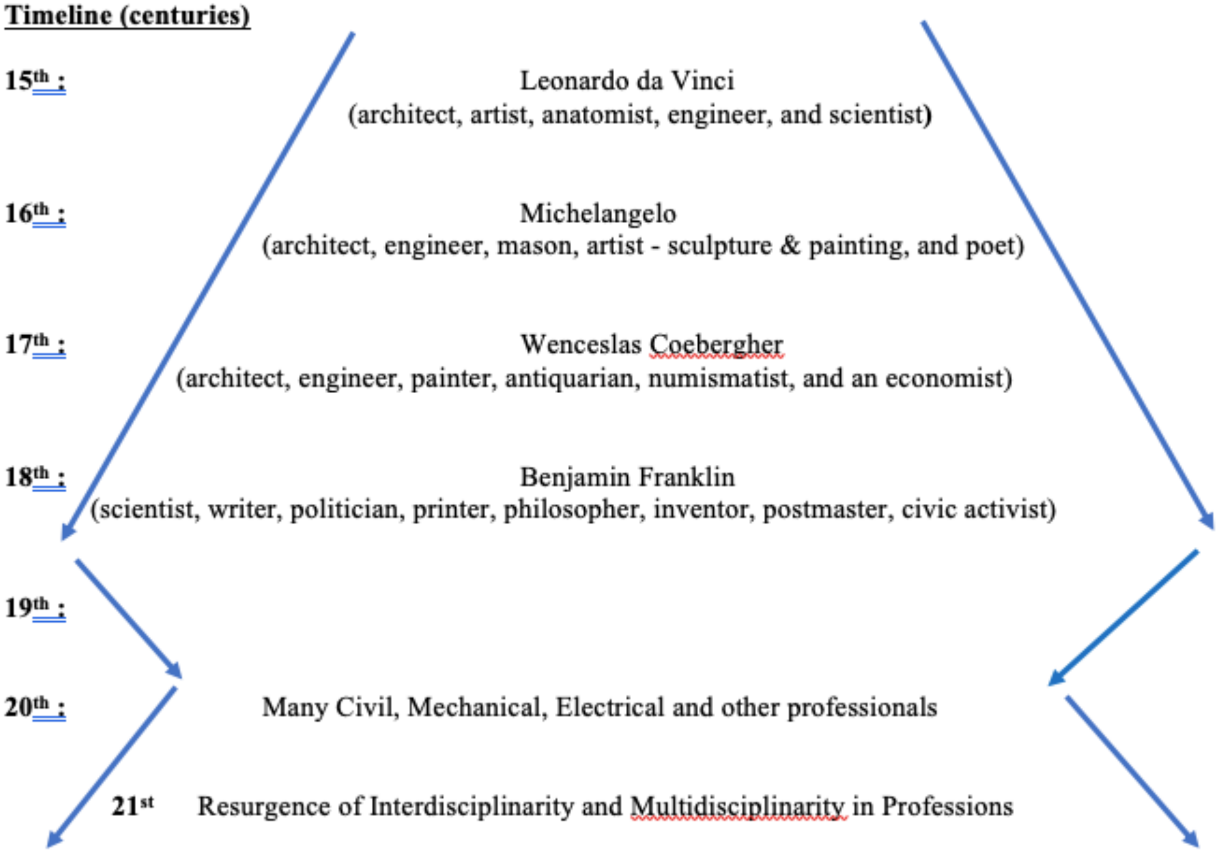


Figure 1: Resurgence of Interdisciplinarity

With the evolution and explosion of knowledge, and the development of the first two industrial revolutions, a growth of specialization in respective field of expertise began emerging in the nineteenth century. Stalwarts like Henry Ford, Max Weber, Nicola Tesla, and George Westinghouse not only focused on engineering but were also entrepreneurs in their own right. The twentieth century saw the rise of the silos in engineering fields; specializations were required to develop the respective engineering disciplines. Advanced technology such as microelectronics and personal computers served as a major catalyst in the growth of the respective discipline during the third industrial revolution.

With the advent of the fourth industrial revolution, we are beginning to see the expansive return of interdisciplinarity across engineering fields [4]. The emerging technology is creating a platform for this disruption. From a pedagogical perspective, two distinct types of interdisciplinary approaches are identified: 1) Bolstering of existing fields with infusion of technological knowledge for example, inclusion of emerging technologies such as artificial intelligence (AI), Internet-of-Things (IoT), and Robotics as a part of the course curriculum. and 2) Evolution of hybrid fields combining two or more existing fields for example humanitarian engineering which combines engineering with social science. Industry applications of these changes are explored in following two cases studies; 1) at a product level: automotive industry and 2) at a system level: transformation of existing cities to a smart city. The engineering educational curriculum of the third decade of the 21st century is proposed to be as follows: 1) Creation of new curriculum to incorporate hybrid education 2) Use of new teaching tools to offer flexibility to students and 3) Proposing interdisciplinary within and across programs between different engineering disciplines.

Multidisciplinary, Interdisciplinarity and Transdisciplinary:

As noted in Figure 1, multidisciplinarity is not a new phenomenon while interdisciplinarity is a growing trend. However, there is a lack of consensus in the literature as to the definition of ‘‘interdisciplinarity’’. Stokols et al. [5] provided distinct definitions describing the levels of union among different disciplines such as interdisciplinary, multidisciplinary, cross disciplinary, and transdisciplinary science. In a multidisciplinary project, participants work independently using their own discipline-specific knowledge to address a common problem. Relatedly, a multidisciplinary individual has knowledge in two or more academic disciplines as we have noted earlier in case of Leonardo da Vinci, Michelangelo, Benjamin Franklin and others. In an interdisciplinary project, participants work jointly to address a common problem applying their own disciplinary perspective. Transdisciplinarity is achieved when participants from different field jointly develop and use a unified and holistic concept, theories and methodology for a unique problem. Multi-, Inter- and Transdisciplinary reflect a continuum of increasing levels of involvement by multiple disciplines [6]. Interdisciplinarity will be used here in a general sense to include inter, multi, and transdisciplinarity (see Figure 2).

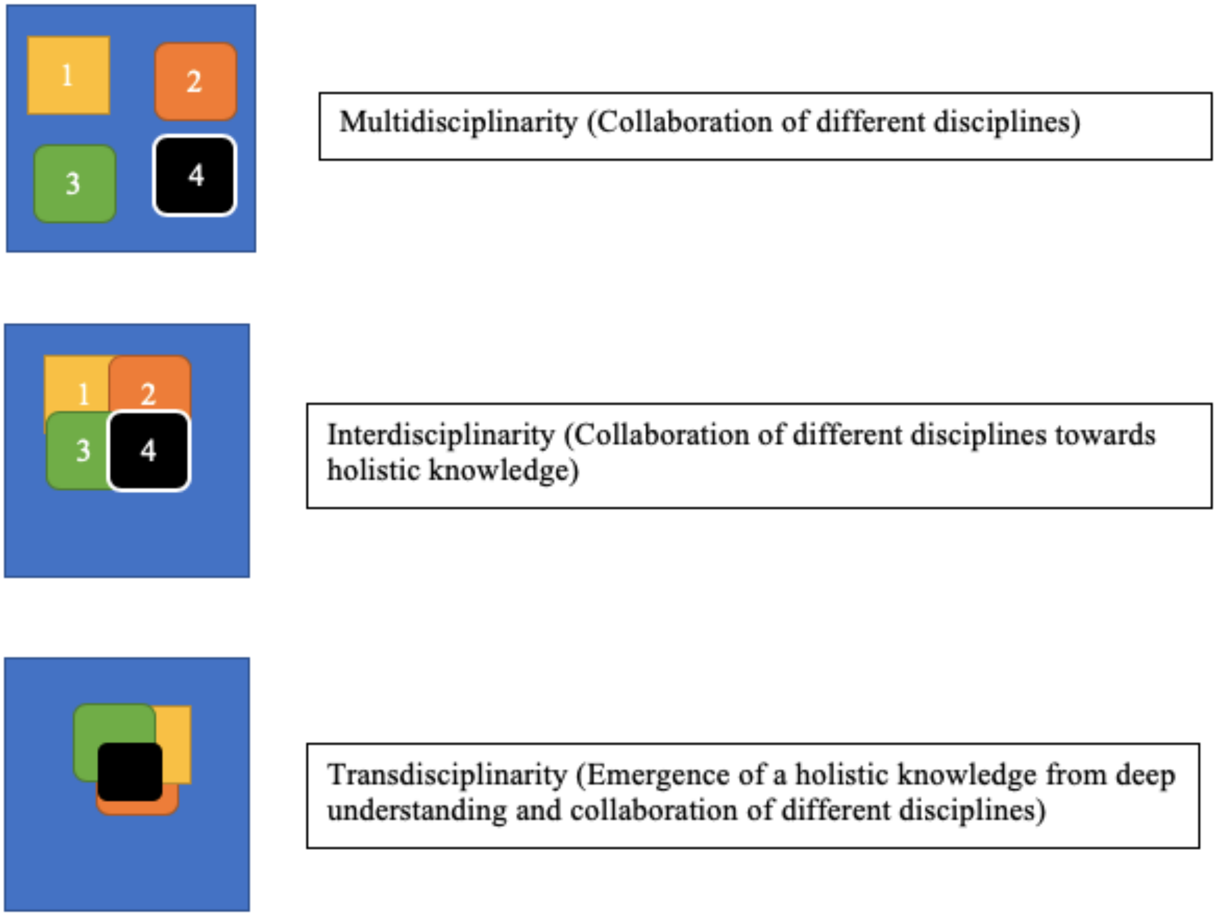


Figure 2: Multidisciplinary, Interdisciplinary and Transdisciplinary

With the evolution and explosion of knowledge, during the first industrial revolutions, a growth of specialization in respective field of expertise began emerging. The main fields of engineering were established as mechanical, mining/metallurgy, civil, electrical and electronics, and chemical engineering during eighteenth and nineteenth century, since these disciplines were essential for civilization to prosper in a modern world during the second and third industrial revolutions [7]. Engineering education in nineteenth and the first half of the twentieth centuries continued to grow in silos. Interdisciplinarity was a rare phenomenon in engineering education during these periods, for example: most of mechanical engineers had no opportunity to learn much about medical field unless they studied to become medical doctors.

Breakthroughs in new technologies such as microelectronics and computer science served as a major catalyst in the growth of third industrial revolution. By mid-twentieth century, a conversation on interdisciplinary started to appear. It was recognized that the ever-increasing demands for improved materials properties were best delivered from an interdisciplinary approach [8]. Particularly, after Russian launched Sputnik in 1957, the United States acknowledged the demand for Material Science and Engineering discipline to progress in defense and nuclear industries [9].

Researchers from different field started sharing their knowledge. Industry supported the higher education in engineering and related fields. Engineering students enrolled in graduate studies in variety of fields such as medicine, business and other engineering field. Personal computers and Internet opened up communication and knowledge sharing opportunities. New innovation across different disciplines started to appear – for example: application of robotics in surgery, ipod and ipad, etc. Curiosity and opportunity were the keys to breaking silos across disciplines.

As noted earlier that interdisciplinarity is not a new phenomenon [10]. However, it appears to be an essential component in engineering education in the 21st century, when new opportunities are being presented by the emerging technologies of this 4th industrial revolution. Despite growing interest in interdisciplinary in research and development, there is a lack of consensus in the definition of interdisciplinarity [11]. In addition to interdisciplinarity, there are additional terms such as multidisciplinarity, crossdisciplinarity, and transdisciplinarity [5] [12]. However, all of them involve working with more than one discipline. We'll explore interdisciplinarity in a sense of knowledge creation by converging domains of different fields ranging from engineering, social science, medicine, business and more.

As described by Cherry Murray, Former Dean Harvard School of Engineering and Applied Science that engineering education will experience "convergence" with other disciplines to solve difficult issues of 21st century and engineers are likely to be "T-shaped thinker," deep in one field, but able to work across all field and able to communicate well. She predicted the "convergence" of knowledge in the domains of engineering disciplines [13].

Intersection of the Digital, Physical and Biological Domains in IR 4.0

As described earlier, there was an urgency in developing different fields of expertise during the first two industrial revolutions. During the third industrial revolution, new discoveries in individual field slowed down, and researchers and industry partners started exploring outside their fields. By the end of the 20th century, project-based work with multi-disciplinary teams appeared to drive innovation. In addition, several emerging technologies appeared at the beginning of the 21st century to revolutionize the Industry and the society.

According to the *World Economic Forum*, the fourth industrial revolution (IR 4.0) is being built upon the infusion of physical, digital, and biological spheres, and it is changing how we live, learn and work. Billions of people are connected via mobile devices with ever-growing processing power, storage capacity and access to knowledge. Technological breakthroughs such as artificial intelligence, robotics, Internet-of things, nanotechnology, and many more are encouraging the changes in entire system of production, management, and governance. blurring the lines between fields of expertise at an exponential pace. Figure 3 provides some of the examples at the intersection of the Digital, Physical and Biological Domains.

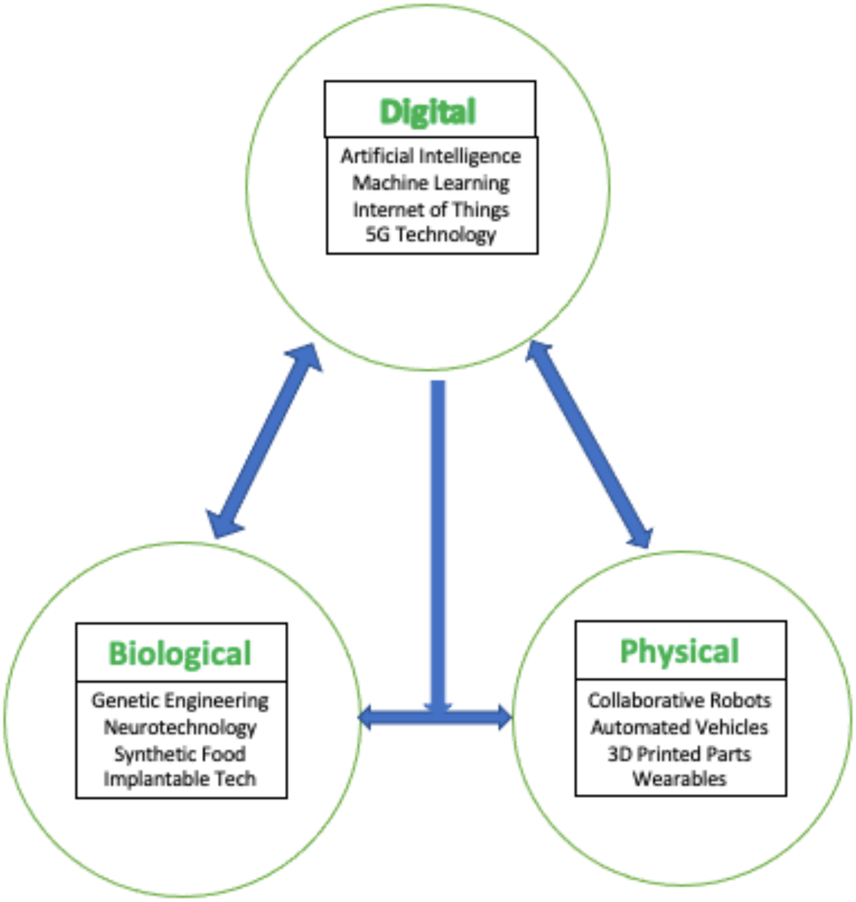


Figure 3: Intersection of the Digital, Physical and Biological Domains

Two Pedagogical Approaches:

From a pedagogical perspective, two distinct types of interdisciplinary approaches are identified: 1) Bolstering of existing fields with infusion of technological knowledge, and 2) Evolution of hybrid fields combining two or more existing fields. Inclusion of emerging technologies such as artificial intelligence (AI), Internet-of-Things (IoT), and Robotics are essential for both options.

The Medical profession has been a part of the human society since evolution. However, medical practices were revolutionized in the 19th century by advances in chemistry, laboratory techniques, and equipment. public health measures, rise of modern medicine based on scientific research, use of statistical approach in epidemiology reduced the death rates and longevity grew in nineteenth and twentieth century. Research and practice in medical field were limited to medical professionals only until the early part of the 20th century. One of the early interdisciplinary researchers, Francis Crick was a molecular biologist, biophysicist and neurologist. He received Nobel prize in 1962 for physiology, with James Watson, another microbiologist for discovering double helix structure of DNA [14].

More interdisciplinary research grew since the mid 20th century. For example, in the social sciences, Alfred Chandler of Harvard Business School founded the discipline of Business History in the 1960s [15]. The "father of biomechanics, Dr. Yuan-Cheng Fung blended medical, biology and engineering principles to develop a new field – Biomedical Engineering or Bio-engineering during mid- to-late 1960s. He developed mechanics for soft tissues [16] which resulted in tissue engineering. Over the years Bioengineering has developed many branches besides tissue engineering such as genetic engineering, neural engineering, pharmaceutical engineering, and bioinformatics. The Bioengineering field provides more options for medical practitioners and their patients beyond traditional treatment of organ replacement. Researchers have been using emerging technology such as 3D printing to produce new human tissues, organs such as ear, bladder, blood vessels, heart, liver and more [17] [18].

Medical robotics is a fast-growing industry. The American Society of Mechanical Engineers (*ASME*) has reported an expected growth of medical robotics to reach to $20 billion by 2023. Some of the applications of robotics in Medicine include: Telepresence, Surgical Assistants, Rehabilitation Robots, Medical Transportation Robots, Sanitation and Disinfection Robots and Robotic Prescription Dispensing Systems[19], with fancy names such as: Some of the latest surgical robots are: da-Vinci surgical robot, Xenex Germ-Zapping Robot, PARO Therapeutic Robot, CyberKnife etc. The demand for surgical robots is growing worldwide, Development of miniature snake-like surgical robots are appearing in engineering research magazines [20].

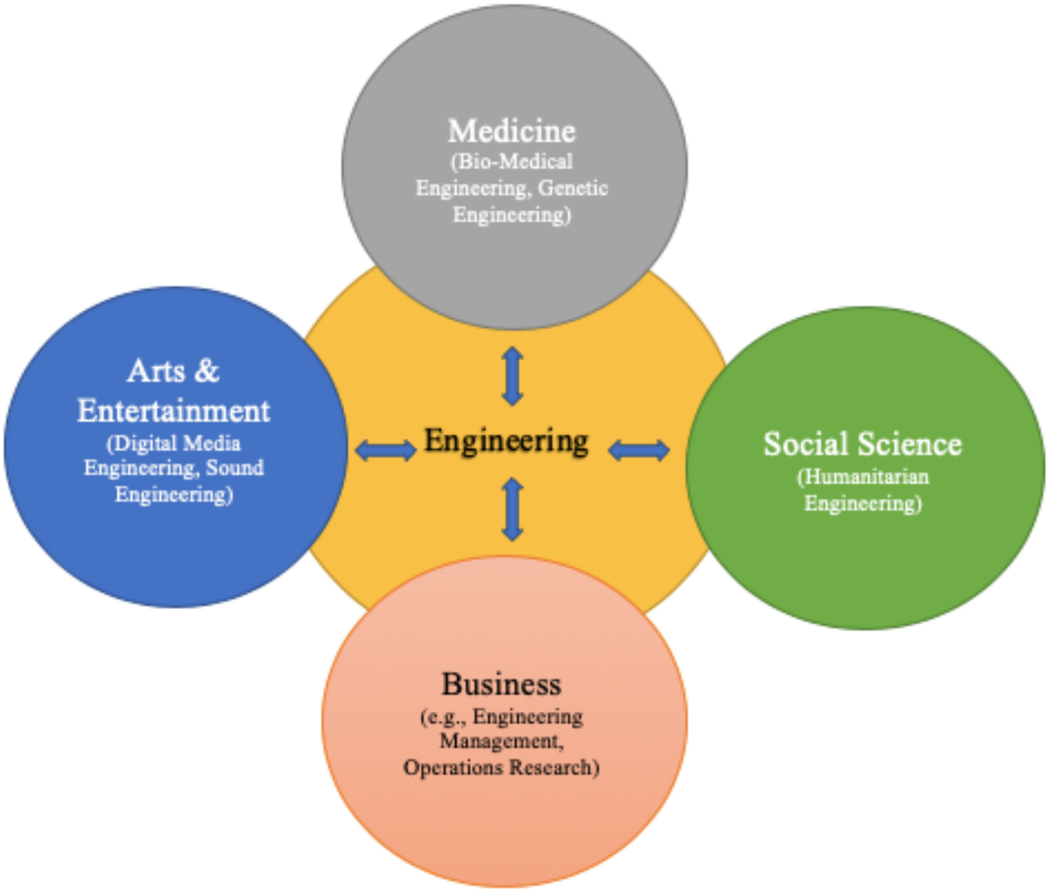
Bob Langer has been a leader in interdisciplinary research. The Langer Lab has become one of the most productive research facilities in the world under his supervision. He works on highly collaborative, and high-impact research topics. He has undergraduate and graduate degrees in Chemical Engineering. However, he has more than 1,100 current and pending patents, and have been licensed or sublicensed to some 300 pharmaceutical, chemical, biotechnology, and medical device companies. His remarkable productivity in medical field has earned him a nickname of "Edison of Medicine" [21].

Another pioneer, Donald A. B. Lindberg was committed to his visionary ideas of applying computer technology to healthcare. A pathologist by his medical training he was a visionary and became a leader in the use of computers in medicine. He was instrumental in establishing the *American Medical Informatics Association* and became the Founding President. His pioneering work in biomedical research and health information has contributed globally in medical informatics, patient care, cancer research, molecular biology, and other educational programs. He served as a director of National Library of Medicine (NLM) for more than 30 years [22].

Another contributor to medical field, Sangeeta Bhatia whose educational background covers bio medical, mechanical and nanomaterial knowledge resulting in finding a way liver cells functioning outside of the human body. She and her coworkers have also used techniques from 3D printing to create a lattice of sugar as a framework for a synthetic vascular system with the goal of supporting larger tissue structures such as an artificial liver [23][24][25]. Bhatia holds a number of patents for both clinical and biotechnological applications of engineering principles.

A team at Princeton University, led by Associate Professor of Mechanical and Aerospace Engineering Michael McAlpine, used 3D printing technology to make a functional ear from calf cells and electronic materials [26]. Padmasree Warrior has been educated as a Chemical Engineer with a Masters' degree from Cornell and joined *Motorola* in 1984. She worked there for more than two decades before joining *Cisco* as Chief Technology and Strategy Officer. Later, she moved from *Cisco* to build autonomous Electric Vehicle company for a company called *NIO* Inc., [27]. Her career illustrates the nature of modern-age employment as an interdisciplinary engineering manager.

These examples provide a glimpse towards the future of interdisciplinarity. Breaking the silos of the disciplines and providing engineering students with holistic knowledge will continue to create a seismic change in fostering innovation and shaping technological breakthrough (see Figure 4).



<u>Figure 4: Interdisciplinarity between different Disciplines</u>

Next, interdisciplinarity in two major domains; a major durable product (automobiles) and a complex system (smart cities) is discussed.

Interdisciplinarity at the Product Level: Automobiles

One of the industries where mechanical engineers have been making a difference over the past century is the auto industry. Discovery of a superior design for a four-stroke internal combustion engine in the late nineteenth century was a mechanical engineering triumph and the foundation for the automobile industry for decades to come. This industry in the United States prospered due to mass production of gasoline powered automobile, availability of superior roads and highways, and inexpensive gasoline. By the mid-twentieth century the Big Three (*GM*, *Ford*, & *Chrysler*) dominated the auto industry in the United States. Automotive manufacturing became the largest industry in the US and helped it becoming the economic superpower [28]. Growth of auto industries led to increase demand for mechanical engineers and this discipline flourished during the first two industrial revolutions.

Electrical Engineering education was first offered in 1882 in MIT [29] and much later Computer Science and Engineering was first offered in a century later in 1971 at Case Western Reserve University [30]. Both of these fields have made significant contribution to the advancement of the modern automobile. Continuous innovations over the years such as automatic transmission, suspension design, chassis design, V8 engine, seatbelts, air-conditioning, rack and pinion steering system, power steering, power brakes, entertainment system, and many more have made the automobile more efficient, safer to drive, and affordable. Nanoparticle rich materials such as nanofluids, nanofibers were introduced in auto parts to improve auto body and performance. By the end of the 20st century, many automated features such as power steering and brakes, heated seats, etc. are being added to enhance robustness and efficiency of the automobile and increase safety and convenience for consumers. By the end of the twentieth century the numbers of computer software engineer surpassed number of mechanical engineers.

Computers became an intrinsic part of an automobile; for example, auto mechanics had to used computers connected to the car's computer system for running diagnostics for defects and other precautionary measures. Thus, automobiles became primarily a computer-controlled machine, rather than a mechanical marvel. These innovations were achieved using by a team of engineers with knowledge in different engineering disciplines such as mechanical, electrical & electronics engineers, material science, and computer science (See Figure 5).

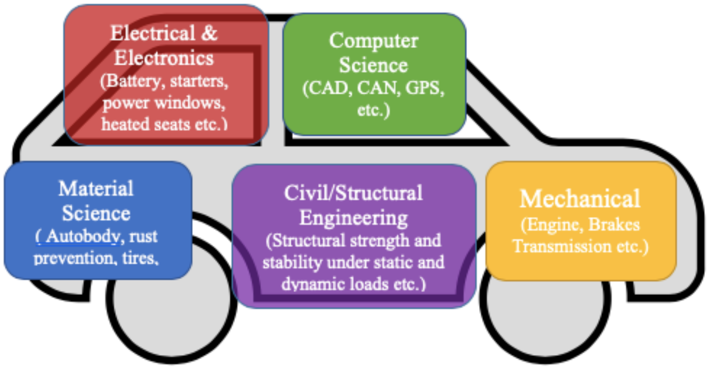


Figure 5: Interdisciplinary Engineering in Building Automobile

The demand for computer science and engineering continues to grow with innovation in internet, data collection and storage facilities, knowledge sharing opportunities and more. The Fourth industrial revolution has opened up radically new possibilities for automobile industry. It is a challenging time for traditional automobile companies. In the face of climate change consumers are concerned with using gasoline as a fuel for transportation. Emerging technologies combined with consumer interests in sustainable transportation options have brought back Electric Vehicles (EVs), along with other alternative power sources. Many new car companies brought exciting options to the consumers - *Coda Automotive*, *Wheego Electric Cars*, *Tesla Motors*, *Fisker Automotive* were among a few [31]. Consumer interests in these new sustainable yet affordable automobile options have forced traditional companies to invest in research and produce EVs and other sustainable vehicles. A few examples of variety of options and their comparison with gasoline engines are shown in the Table 1 below:

Table 1: Comparison between Automobiles with Different Fuel Sources

Technology	Auto Model	Fuel Source	Mileage	Efficiency (km/MJ)
Natural Gas Engine	Honda CNG	Natural Gas	35 mpg	0.37
Hydrogen Fuel Cell	Honda FCX	Natural Gas	64 mpg	0.57
Diesel Engine	VW Jetta	Crude Oil	50 mpg	0.53
Gasoline Engine	Honda Civic VX	Crude Oil	51 mpg	0.63
Hybrid (Gas/Electric)	Toyota Prius	Crude Oil	55 mpg	0.68
Electric	Tesla Roadster	Natural Gas	110 Wh/km	2.18

Source: http://idc-online.com/technical_references/pdfs/electrical_engineering/Tesla_Motors.pdf

In 2020, some of the best EVs are offered by a combination of traditional and new auto companies such as *BMW, Chevrolet, Kia, Nissan, Tesla*, etc. [32]. *Toyota* announced to provide "3700 mobility products and/or vehicles for the 2020 Olympics, 90 percent of which will be electrified." [32]. According to an estimate by analysts from *Bloomberg,* global auto-companies will sell about 2.5 million electric passenger cars worldwide in 2020 [34]. The main power-sources of these alternative vehicles are hydrogen fuel cell, natural gas, battery, and gas-electric hybrid, instead of gas-fueled combustion engine from the past.

Besides EVs, digital technologies such as IoT, AI and other smart technologies are in the verge of disrupting the automobile industry in bringing autonomous cars in the market. *Tesla* and *Waymo (Google)* are the front runners. *Waymo* reported of 20 million miles of autonomous driving at the beginning of 2020. Many Other non-traditional automobile companies such as *Amazon, Apple, Aptiv, Baidu, Nvidia, Uber* are competing with traditional automakers such as *Audi, Honda, GM, Huawei, Mercedez-Benz*, etc. for the market share [35].

The success for autonomous cars involves smart technology involves digital map, highly reliable and accurate sensing technology for connected systems, powerful computing, machine learning among others. Some of the other major issues besides the autonomous driving technology are consumer privacy, cybersecurity, safety regulation, ethical issues, which need to be resolved in order to develop autonomous vehicles as a consumer product [36]. Making cars

for the 21st century involves knowledge in computer science, electrical, chemical, material science, nanotechnology, bioengineering, in addition to mechanical engineering. In addition, manufacturing techniques in the auto industries require upgrading by investing in smart manufacturing such as 3D Printing, IoT, AI, and Robotics. The power of smart manufacturing comes from collecting and analyzing data, thus understanding how to optimize the manufacturing process and thus make it more profitable and sustainable [37].
Hence, it is important to modify engineering curriculum to include interdisciplinary knowledge at the undergraduate level to meet the need of the Automotive Industry of 21st century.

Interdisciplinarity at the System Level: Smart Cities

Civil engineering is another engineering discipline which grew along with mechanical and electrical engineering throughout the industrial revolutions to help society and industry with their various needs for building structures, roads and highways, provides utilities such as water and sanitation. Urbanization was possible primarily because of civil engineers. By 2030, the world's population is projected to be 8.5 billion. Many cities in the world are growing rapidly as people move to cities in search of better employment opportunities [38]. The fast growth of megacities (population of more than 10 million people) is stretching the ability of city governments in providing the basic necessities. Data shows that by 2025 additional 80 billion metric tons of municipal water will be needed to serve public demand. Demand for other resources such as energy, air quality, traffic flow will continue to rise fast and will impact the quality of life in cities [39]. To resolve these immense challenges the urban management authorities are in the process of making the cities smart. Smart cities of 21st century are envisioned to be digitally connected with infrastructure and operations, transportation including parking, waste management and residents. Providing safe, secured and green environment to city-dwellers are the goal of smart cities. Internet of Things (IoT) is perceived as the key technology in achieving smart cities [40][41].

According to IMD Smart City Index of 2019, Singapore, Zurich, Oslo, Geneva, and Copenhagen are the top five smart cities respectively [42] (see Table 2). San Francisco is the highest-ranking US city that ranked 12th in the list. Singapore achieved success by using digital technologies to create safe communities and to provide more opportunities for the citizens. The smart initiatives in Singapore are based on three pillars – digital economy, digital government and digital society. Singapore used holistic strategy involving technology, regulation, education and support at all levels of government to create a top ranked smart city [43].

Table 2: Ranking and Rating of Major Smart Cities in the World

Overall Ranking	City	Overall Rating
1	Singapore	AAA
2	Zurich	AAA
3	Oslo	AA
4	Geneva	AA
5	Copenhagen	AA
6	Auckland	A
7	Taipei City	A
8	Helsinki	A
9	Bilbao	A
10	Dusseldorf	A
11	Amsterdam	A
12	San Francisco	A
13	Vancouver	A
14	Sydney	A
15	Toronto	A
16	Montreal	A
17	Vienna	BBB
18	Bologna	BBB
19	Prague	BBB
20	London	BBB
21	Madrid	BBB
22	Milan	BBB
23	Lyon	BBB
24	Melbourne	BBB
25	Stockholm	BBB

Source : https://www.imd.org/smart-city-observatory/smart-city-index/

Similarly, Zurich adopted digital transformation to make the city smart. Geoportal, eCitypläne, Digital twin of the city use IoT and Holoplanning through augmented reality application are used for urban planning and construction projects. A city-wide network was created for application of Internet of Things for collection of data and information. Future public transportation are planned to be electric powered or autonomous vehicles. Smart medicine in Zurich implies interdisciplinary cooperation between various organizations to make healthcare system more efficient, evidence based, and needs oriented (see Table 3) [44].

Table 3: Exemplar Projects in Zurich’s Smart City Management: An Interdisciplinary Approach

	Engineering Disciplines					
Smart Projects	**Civil**	**Mechanical**	**Environmental**	**Electrical**	**Computer Science**	**Transportation**
Geoportal, Digital Twin, eCitypläne	**				***	
Emobility, Ride Sharing		**	**	**	***	***
Autonomous Driving		**	**	**	***	**
EnerGIS	*		***		***	
LoRaWAN			**		***	**
Holoplanning	**				***	

***	denotes significant contribution to smart projects
**	denotes medium contribution to smart projects
*	denotes minimal contribution to smart projects

Source: https://www.stadt-zuerich.ch/portal/de/index/politik_u_recht/stadtrat/weitere-politikfelder/smartcity.html

Cisco is one of the front runners in designing and implementing this vision of smart city throughout the world. It has invested $1 billion to fund existing cities to help creating digital transformation [45]. According to the firm, “A smart city uses digital technology to connect, protect, and enhance the lives of citizens. IoT sensors, video cameras, social media, and other inputs act as a nervous system, providing the city operator and citizens with constant feedback so they can make informed decisions.” [46]. A “Living Lab” of smart technologies has been created in the town of Cary in North Carolina. The living lab projects include a community center parking lot outfitted with sensors to tell city officials when a parking space is occupied and for how long [47]. Austin, Washington DC, Albuquerque, N.M., Phoenix, San Diego are a few of the Smart Gigabit Communities (SGC) which receives support from the National Science Foundation to use its physical and wireless network infrastructure as an enabler of smart applications to solve specific community problems [48].

Traditionally Urban Architects and Civil Engineers are trained to build infrastructure for cities including design and build transportation systems, sanitary and water supply among others. Infrastructure continued to be a central piece of a smart city. Yet, the connection and integration of all systems makes the city "smart." [49]. Digitally connected cities with smart home, and smart transportation systems need engineers with interdisciplinary knowledge to keep up with the need of 21st century. Construction Engineering discipline is also in the process of transformation. The use of 3D printing technology, which has been widely accepted in the manufacturing industry or the medical field is currently being used to build homes. For example, USA today reported on Dec 13, 2019 world's first 3D printed homes in a Mexican neighborhood with a goal of end global homelessness (see Figure 6). The largest 3D printed building is unveiled in Dubai recently – a two story building with 640 sq. meter and 9.5 meter tall [50]. Workers' Safety has always been a concern in construction industry. Various types of wearables are currently being used to keep construction workers safe. Wearable technologies use sensors, computers and electronics in portable high-tech devices that can be carried by the employees. Wearables are designed to collect and deliver data about the worker's environment and detect and warn employees of the potential for injury [51].

Source: USA today: 2019 https://www.usatoday.com/story/tech/2019/12/13/3-d-printed-home-neighborhood-rural-mexico-first-world/2640942001/

Figure 6: 3D Printed Neighborhood in Mexico

Revolutionizing the Engineering Educational System:

Given the exponential developments in interdisciplinarity across engineering and other disciplines, several pedagogical approaches are offered to upgrade the educational system of the third decade of the 21st century as follows:

1) Create new curriculum to incorporate hybrid education

Engineers in 21st century faces the challenges and opportunities to provide for long-term well-being of society. They will be shaping the future of our planet by solving complex technological and humanitarian problems concerning physical, economic, political, legal and cultural in diverse fields such as energy, health, environment and more. Many engineering schools have already started creating interdisciplinary curriculum for undergraduate students. For example: MIT offers Interdisciplinary degrees in several fields, including: Computation and Cognition; Computer Science and Molecular Biology; Humanities and engineering and Urban Science and Planning with Computer Science. In addition, students have the option of picking a Minor from more than a dozen diverse subjects ranging from astronomy, public policy to women's and gender studies to supplement their Engineering major [52].

Project based experiential learning should also be encouraged: Many universities require undergraduate students to complete a capstone project in their senior year. The students pair up with an industry partner to pursue project-based learning. They are mostly unidisciplinary, with a focus on civil or mechanical engineering. However, some projects require interdisciplinary knowledge, which are achieved by grouping students and mentors from different disciplines. For example, many leading manufacturing companies, pharmaceutical and medical firms, consulting practices, utilities, and government agencies collaborate in senior design projects at University of Connecticut. Some of the past projects required interdisciplinary knowledge from mechanical, electrical and computer science, material science and business as well [53].

2) Use new teaching tools and offer flexibility to students

Teaching tools have progressed over the years along with course materials. Modern engineering labs include Desktop 3D printers, robots, Desktop CNC machines, automated measurement machines and more. The universality of these new tools makes them essential for many different disciplines, and hence useful for interdisciplinary teaching. Manufacturing companies are experimenting with the use of virtual reality for the purpose of communication and collaboration in their worldwide manufacturing facilities and corporate offices. Many types of virtual reality educational software, ranging from manufacturing to human body can also be used to teach interdisciplinary subjects to students from different disciplines.

Some of the Engineering programs are also offering flexibility for individually designed majors in addition to offering traditional and interdisciplinary programs as well. For example; Stanford provides interdisciplinary programs such as science, technology and society, or symbolic systems in addition to traditional fields of civil, or mechanical engineering. Engineering students are also allowed to design their own major with help of faculty advisors [54]. Brown University also provide undergraduate students the option to design a personalized major according to its open curriculum [55]. Similar flexibility will provide great opportunities for creativity and innovation for engineering students in the 21st century.

3) Propose joint programs between different schools within and across Engineering disciplines.

Collaboration amongst researchers has been vital to innovation and interdisciplinarity. However, it is still rare at the undergraduate level except for a few universities to offer partnership within and outside. The University of Connecticut offers an undergraduate degree called Management and Engineering for Manufacturing (MEM) which is an interdisciplinary degree offered jointly from school of Engineering and school of Business [56]. Based on our content analysis of major Engineering Programs in the United States, a summary of program descriptions, level of instruction, interdisciplinary fields and its exemplary combinations is provided in Table 4. Most of these are fairly recent initiatives, hence it is too early to evaluate the outcomes. However, in recent years, the MEM program at the University of Connecticut has been successful in achieving 100 percent job placement for undergraduates with highest or near highest starting salary in the School of Engineering.

Further initiatives have been taken to explore and build collaborative educational curricula amongst Universities from different countries such as study abroad programs. These programs are popular to students and can be used to expand interdisciplinary education. However, some of the factors such as, proper credit transfer, and availability of required courses needed to be sorted out to make these opportunities appealing to students.

Conclusion:

With the rapid advancements in technologies in the age of IR 4.0, the pedagogical approaches in the engineering disciplines will have to adapt to the increasing focus on interdisciplinarity. The employment landscape is undergoing a massive shift mandating such advanced skills increasingly important. It is equally important for accrediting bodies like *Accreditation Board for Engineering and Technology, Inc. (ABET)* [57] to update their evaluation criteria in giving approval for engineering programs that are created in collaboration with experts from Industry, academia, and government. State legislated licensure boards can also participate in emphasizing the need for interdisciplinarity in engineering education.

The eminent Economic Sociologist, Max Weber, emphasized productivity through specialization [58]. Yet, since the 3rd Industrial Revolution, most of the advancements have been based on experiential education and the use of interdisciplinary work. This approach is still very much a work-in-progress in academia but with the immense digital and technological breakthroughs, it is gathering steam within the STEM fields. The growth of the silo approach over the past few decades have now transitioned to the emergence of interdisciplinary expertise to meet the challenge of designing and building the connected systems in the 21st century.

Table 4: Examples of Recent Initiatives in Interdisciplinary Engineering Programs

Institution	Program Descriptions	Level of Instruction	Interdisciplinary Fields	Exemplary Combinations
University of Connecticut	Interdisciplinary Graduate Program	Undergraduate	Management and Engineering for Manufacturing	Engineering + Business+ Manufacturing
	Krenicki Arts and Engineering Institute	Undergraduate	Fine Arts and Engineering	Arts + Engineering
MIT	Interdisciplinary Programs in Engineering	Graduate	Computational Science and Engineering	Aeronautics + Astronautics+ Chemical + Civil+ Environmental + Mathematics + Mechanical + Nuclear science
			Computational and Systems Biology	Biology + Engineering+ Computer science
			Social Engineering Systems	Mathematical modeling + Data analysis + Energy systems+ Finance + Health care+ Social networks + Urban systems
UC Berkeley	Jacobs Institute for Design Innovation	Graduate	Design and Manufacturing	Automation+ Rapid prototyping + Team-based learning + Commercial development
	MDes Program	Graduate		Engineering + Environment
University of Michigan	Interdisciplinary Graduate Program	Graduate	Applied Physics	Physics + Emerging technology
			Macromolecular Sc. & Engineering	Polymer Science + Engineering
			Robotics	Collaborative Robotics + Cross-disciplinary Robotics
			Tauber Institute if Global Operations	Business + Engineering
Purdue University	Multidisciplinary Engineering Studies	Undergraduate	Humanitarian Engineering	Engineering + Medical + Humanitarian
			Visual Design Engineering	Art+ Engineering

Selected References:

[1] W. Isaacson, *Leonardo da Vinci*., New York, NY: Simon and Schuster, 2017.

[2] H. Hibbard, *Michelangelo*. New York, NY: Routledge, 2018.

[3] M. D. Mumford, "Social innovation: ten cases from Benjamin Franklin," *Creativity Research Journal*, vol. *14*, no. 2, pp.253-266, 2002.

[4] M. Abramovici, J. C. Göbel, and M. Neges, "Smart engineering as enabler for the 4th industrial revolution," *Integrated systems: Innovations and applications,* pp.163-170, 2015. Springer, Cham.

[5] D. Stokols, J. Fuqua, J. Gress, R. Harvey, K. Phillips, L. Baezconde-Garbanati, et al., "Evaluating transdisciplinary science," *Nicotine & Tobacco Research,* vol. *5*, pp. S21–S39, 2003.

[6] B. C. Choi, and A. W. Pak, "Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness," *Clinical and investigative medicine*, vol. *29* no. 6, pp. 351, 2006.

[7] R. J. Smith, "History of Engineering," *Encyclopaedia Britannica.* [Online] Available: https://www.britannica.com/technology/engineering [Accessed Feb. 2, 2020]

[8] I. J. Polmear, "Metallurgy or Materials Science--Evolution or Revolution?" *J. Australian Inst. Metals*, vol. 17 no. 3, pp.129-141, 1972.

[9] C. Ferguson, "Historical Introduction to the Development of Material Science and Engineering as a teaching discipline." 2006. [Online] Available from the UKCME: https://www.materials.ac.uk/pub/Materials-History-Intro.pdf [Accessed Feb. 2, 2020]

[10] J.T. Klein, "Interdisciplinarity: History, theory, and practice," *Wayne state university press*. 1990

[11] K. Huutoniemi, J. T. Klein, H. Bruun, and J. Hukkinen, "Analyzing interdisciplinarity: Typology and indicators," *Research Policy*, vol. 39 no.1, pp.79-88. 2010.

[12] A. R. Jensenius, "Disciplinarities: intra, cross, multi, inter, trans", 2012, [Online] Available: https://www.arj.no/.2012/03/12/disciplinarities-2 (Accessed Feb. 2, 2020)

[13] Mishra, P., Terry, C. A., & Henriksen, D. (2013). Square peg, round hole, good engineering. *TechTrends*, *57*(2), 22.

[14] Nobel Media AB 2020, "The Nobel Prize in Physiology or Medicine 1962", Sun. 2 Feb 2020. [Online] Available: https://www.nobelprize.org/prizes/medicine/1962/summary/

[15] S. Silverthorne, “Remembering Alfred Chandler,” 15 JUN 2007, [Online] Available: https://hbswk.hbs.edu/item/remembering-alfred-chandler(Accessed Feb. 2, 2020)

[16] Chien, S. (Ed.). (2010). *Tributes to Yuan-Cheng Fung on His 90th Birthday: Biomechanics: from Molecules to Man*. World Scientific.

[17] A. Danigelis, “10 Bioengineered Body Parts That Could Change Medicine”, July 23, 2013, [Online] Available: (https://mashable.com/2013/07/23/bioengineered-body-parts/) (Accessed Feb. 2, 2020)

[18] Ay, M., Kubat, T., Delilbasi, C., Ekici, B., Yuzbasioglu, H. E., & Hartomacioglu, S. (2013). 3D Bio-CAD modeling of human mandible and fabrication by rapid-prototyping technology. *Usak University Journal of Material Sciences*, 135.

[19] M. Crawford, “Top 6 Robotic Applications in Medicine”, Sep 14. 2016, [Online] Available: https://www.asme.org/topics-resources/content/top-6-robotic-applications-in-medicine) (Accessed Feb. 2, 2020)

[20] Webster, R. J., Okamura, A. M., & Cowan, N. J. (2006, October). Toward active cannulas: Miniature snake-like surgical robots. In *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 2857-2863). IEEE.

[21] S. Prokesch, “ The Edison of Medicine”, March-April 2017, [Online] Available: https://hbr.org/2017/03/the-edison-of-medicine (Accessed Feb. 2, 2020)

[22] F. S. Collins and P. F. Brennan, “Mourning the loss of former NLM Director Donald A.B. Lindberg, M.D.”, Aug 19 2019, [Online] Available: https://www.nih.gov/about-nih/who-we-are/nih-director/statements/mourning-loss-former-nlm-director-donald-ab-lindberg-md (Accessed Feb. 2, 2020)

[23] Allen, J. W., & Bhatia, S. N. (2002). Engineering liver therapies for the future. *Tissue Engineering*, *8*(5), 725-737.

[24] Tsang, V. L., Chen, A. A., Cho, L. M., Jadin, K. D., Sah, R. L., DeLong, S., ... & Bhatia, S. N. (2007). Fabrication of 3D hepatic tissues by additive photopatterning of cellular hydrogels. *The FASEB Journal*, *21*(3), 790-801.

[25] Miller, J. S., Stevens, K. R., Yang, M. T., Baker, B. M., Nguyen, D. H. T., Cohen, D. M., ... & Chaturvedi, R. (2012). Rapid casting of patterned vascular networks for perfusable engineered three-dimensional tissues. *Nature Materials*, *11*(9), 768.

[26] J. Sullivan, " Printable 'bionic' ear melds electronics and biology" May 8, 2013 [Online] Available: https://www.princeton.edu/news/2013/05/08/printable-bionic-ear-melds-electronics-and-biology (Accessed Feb. 2, 2020)

[27] Forbes, "Padmasree Warrior", [Online] Available: https://www.forbes.com/profile/padmasree-warrior/#4e36162165ed (Accessed Feb. 2, 2020)

[28] Ikuta, Y. (2000). *Cruise o matic: automobile advertising of the 1950s*. Chronicle Books. p.18, *MotorBooks International.*

[29] Weber, Ernst; Frederik Nebeker (1994). *The Evolution of Electrical Engineering: A Personal Perspective*. IEEE Press. ISBN 0-7803-1066-7.

[30] Case Western University, [Online] Available:https://engineering.case.edu/eecs/about/history (Accessed Feb. 2, 2020)

[31]D. Carney, "10 new car companies aiming for the big leagues", 2013, [Online] Available: http://www.nbcnews.com/id/40887273/ns/business-autos/t/new-car-companies-aiming-big-leagues/ (Accessed Feb. 2, 2020)

[32] Energysage, "Electric vehicle manufacturers & companies", 7/8/2019, [Online] Available: https://www.energysage.com/electric-vehicles/buyers-guide/top-ev-companies/ (Accessed Feb. 2, 2020)

[33] A. J. Hawkins, "Toyota going all-out with electric vehicles for the 2020 Olympics", August 23, 2019, [Online] Available: https://www.theverge.com/2019/8/23/20830105/toyota-electric-vehicles-2020-olympics-ev-scooter (Accessed Feb. 2, 2020)

[34] W. Mathis, "Cheaper Batteries, More Chargers for Electric Car Buyers in 2020", Jan 13, 2020, [Online] Available: https://www.bloomberg.com/news/articles/2020-01-13/cheaper-batteries-more-chargers-for-electric-car-buyers-in-2020 (Accessed Feb. 2, 2020)

[35]A. Pressman, "Waymo Reaches 20 Million Miles of Autonomous Driving", Jan 7, 2020, [Online] Available: https://fortune.com/2020/01/07/googles-waymo-reaches-20-million-miles-of-autonomous-driving/ (Accessed Feb. 2, 2020)

[36] L. Parker and Abt Associates Inc., "Engineers in the United States: An Overview of the Profession", June 2004, [Online] Available: https://www.nspe.org/sites/default/files/resources/pdfs/blog/Abt-Report-on-Engineering-Profession2.pdf (Accessed Feb. 2, 2020)

[37] P. Raushan, "The Top 7 Things to Know About Smart Manufacturing", Aug 20, 2018, [Online] Available: https://blog.marketresearch.com/the-top-7-things-to-know-about-smart-manufacturing (Accessed Feb. 2, 2020)

[38] Khatoun, R., & Zeadally, S. (2016). Smart cities: Concepts, architectures, research opportunities. *Commun. Acm*, *59*(8), 46-57.)

[39] G. Allee, Intel Corporation, and City of San Jose, "Smart Cities USA", [Online] Available: https://smartamerica.org/teams/smart-cities-usa/ (Accessed Feb. 2, 2020)

[40] (A Review of Smart Cities Based on the Internet of Things Concept Saber Talari 1 , Miadreza Shafie-khah 1,2,*, Pierluigi Siano 2 , Vincenzo Loia 3 , Aurelio Tommasetti 3 and João P. S. Catalão, 2017)

[41] (Hall, R. E., Bowerman, B., Braverman, J., Taylor, J., Todosow, H., & Von Wimmersperg, U. (2000). *The vision of a smart city* (No. BNL-67902; 04042). Brookhaven National Lab., Upton, NY (US).).

[42] IMD World Competitive Center and Singapore University of Tecnology and Design, " IMD and SUTD's unique ranking shows importance of citizens' needs in policymaking, 2019, [Online] Available: https://www.imd.org/smart-city-observatory/smart-city-index/ (Accessed Feb. 2, 2020)

[43] HEREmobility, " Singapore Smart City: A holistic Transformation", [Online] Available: https://mobility.here.com/singapore-smart-city-holistic-transformation (Accessed Feb. 2, 2020)

[44] S. Vorlesen, "Smart City Zurich in English", [Online] Available: https://www.stadt-zuerich.ch/portal/de/index/politik_u_recht/stadtrat/weitere-politikfelder/smartcity/english.html (Accessed Feb. 2, 2020)

[45] Roy, M., & Roy, A. (2019). Nexus of Internet of Things (IoT) and Big Data: Roadmap for Smart Management Systems (SMgS). *IEEE Engineering Management Review*, *47*(2), 53-65.

[46] Anthopoulos, L., Janssen, M., & Weerakkody, V. (2019). A Unified Smart City Model (USCM) for Smart City Conceptualization and Benchmarking. *Smart Cities and Smart Spaces: Concepts, Methodologies, Tools, and Applications*, 247–264. https://doi.org/10.4018/978-1-5225-7030-1.ch011

[47] S. Descant, "Cary, N.C., Tests Smart Technology in Its 'Living Lab' City Campus", Nov 16, 2017, [Online] Available: https://www.govtech.com/fs/Cary-NC-Testing-Smart-Technology-in-its-Living-Lab-city-campus-.html (Accessed Feb. 2, 2020)

[48] D. Haisler, "5 New Cities Become Smart Gigabit Communities", June 17, 2017[Online] Available: https://www.govtech.com/fs/5-New-Cities-Become-Smart-Gigabit-Communities.html (Accessed Feb. 2, 2020)

[49] Monzon, A. (2015, May). Smart cities concept and challenges: Bases for the assessment of smart city projects. In *2015 international conference on smart cities and green ICT systems (SMARTGREENS)* (pp. 1-11). IEEE.

[50] L. Stinson, "World's largest 3D-printed building completed in Dubai", Dec 30, 2019, [Online] Available: https://www.curbed.com/2019/12/30/21035765/world-largest-3d-printed-building-dubai-apis-cor (Accessed Feb. 2, 2020)

[51] D. P. Galbraith, "Construction wearables' futuristic features are more feasible than you think", June 26, 2019, [Online] Available: https://www.constructiondive.com/news/construction-wearables-futuristic-features-are-more-feasible-than-you-thin/557715/ (Accessed Feb. 2, 2020)

[52] MIT, School of Engineering, " Interdisciplinary Program", [Online] Available: https://engineering.mit.edu/academics/graduate/interdisciplinary-programs/ (Accessed Feb. 2, 2020)

[53] UCONN, School of Engineering Senior Design Program, [Online] Available: https://seniordesign.engr.uconn.edu/) (Accessed Feb. 2, 2020)

[54] Stanford, School of Engineering, [Online] Available: https://exploredegrees.stanford.edu/schoolofengineering/#bachelorstext (Accessed Feb. 2, 2020)

[55] Brown, "The Open Curriculum", [Online] Available: https://www.brown.edu/academics/undergraduate/open-curriculum (Accessed Feb. 2, 2020)

[56] UCONN, Management and Engineering for Manufacturing Program, [Online] Available: https://www.mem.uconn.edu/ (Accessed Feb. 2, 2020)

[57] ABET Accreditation, available at www.abet.org [Accessed March 16, 2020]

[58] Weber, Max. 1978 [1909]. Economy and Society: An Outline of Interpretive Sociology, translated by E. Fischoff, edited by G. Roth and C. Wittich. Berkeley: University of California Press.