ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #38097

Industry 4.0 or the Industrial Internet of Things (IIoT) - its future impact on two-year engineering technology education

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Industry 4.0 or the Industrial Internet of Things (IIoT) – its future impact on two-year engineering technology education.

Overview/Background:

The term Industry 4.0 has been in use now for a little over a decade. Introduced in 2011 by a German government project related to a high-tech policy strategy, it was first used to describe a new age of manufacturing. Specifically, the term depicted manufacturing assisted by the latest convergence of technologies such as computers and automation and improved through the use of intelligent and autonomous systems supported by data and machine learning. Since then, the term has been appropriated to refer to a new industrial age and this present use is consistent with how the first three Industrial Revolution eras have been defined by historians. Indeed, during this last decade and continuing today, fundamental shifts have been taking place in how global production and supply chain networks operate through an ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large scale machine-to-machine (M2M) communication, and the Internet of Things (IoT) applications to enable many supportive and essential industrial functions. This technology integration/implementation into industrial environments results in increasing automation, improving timely communications and self-monitoring, and increasing the use of smart machines that can analyze and diagnose process issues without the need for human intervention [1]. More recently, the term Industrial Internet of Things or IIoT has been also employed to indicate an extension of uses of the Internet of Things to other industrial applications and sectors. In this usage, this term's scope has been expanded to cover the breadth of humankind's industrial activities - not just manufacturing. To be sure, one might see other IoT based acronyms such as: Vehicular IoT or VIoT, Internet of Medical Things or IoMT, Agricultural IoT or AIoT, each used to specify particular industrial domains. However, IIoT is an appropriate blanket term used for just about any human industrial endeavor enhanced by an IoT application. Therefore, it is this definition that will be emphasized in this paper. For further clarification, it might prove to be beneficial to define what is meant by the term Internet of Things or IoT. A common definition of IoT is: … describes the network of physical objects—a.k.a. "things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet. Essentially, machines talking to other machines or M2M. It should be further pointed out that the vast majority of IoT applications are in the operational technology (OT) space. Therefore, another definition needs to be offered. A common definition of OT is: … a category of computing and communication systems to manage, monitor, and control industrial operations with a focus on the physical devices and processes that they use. This term has been put into practice to demonstrate the technological and functional differences between traditional IT systems and the Industrial Control Systems environment [2]. This is not to say that industrial systems don't use IT since they most certainly do. However, it is useful to recognize the distinction between IT and OT and the fact that different types of expertise are needed to deal with the specific OT system that is being controlled.

While it takes numerous diverse attributes and workforce skill sets of a country's population to enable an industrialized nation, to achieve consistent economic growth typically requires the more efficient division of labor and the use of technological innovation to solve problems [3]. Most modern nations equate this latter characteristic to a well-educated workforce. Today, in the United States (US), institutions of higher education are charged with educating the scientists, engineers, and technicians that are the vanguard of the industrial sector workforce and the human resources that make us competitive in the world economy. Typically, these individuals are taught various general education topics (generally considered to be essential for the student to become a knowledgeable citizen) and the mathematics and science fundamentals (e.g. calculus, physics, chemistry, etc.) required to be able to comprehend the additional theory and lore pertinent to their particular field of study (i.e. electrical, mechanical, chemical, management, civil and geotechnical engineering). Typically, engineers and scientists study these topics at four-year colleges (undergraduate and post-graduate level) with the aid of higher mathematics (typically, calculus and differential equations) to gain an extensive insight to the theory of the subject matter being studied. The goals of this type of education are to impart skills that enable graduates the ability to solve problems and to be innovative (engineers) and to be able to create new knowledge (scientists). Along the same lines, technicians typically are taught at two-year colleges or vocational schools and utilize less precise algebraic based models of the processes typically found in their specific fields of study (usually related to a certain engineering discipline). The goals of this type of educational pathway are to impart the skills needed to install, update, maintain, and evaluate correct system operation of complex operational technical systems.

Recently, in response to this new era of the Industrial Revolution, this country's educators, industries, national government advisory boards, and numerous thought leaders have begun to earnestly question how we are educating our industrial workforce and what we collectively need to do as a country to maintain our competitive edge. In 2020, the National Science Board (NSB) issued the report: Vision 2030. This report outlined a potential roadmap for actions the NSB and the National Science Foundation (NSF) need to follow if the US is to maintain its status as the innovation leader in the world [4]. Certainly, one of the most publicly recognized outgrowths of this report and other improvement efforts is embodied in the idea of the promotion of STEM (science, technology, engineering, and mathematics) education at the K-12 level and emphasis on STEM majors at the college level. Indeed, if one Googles "Vision 2030", one will discover numerous other narratives/reports of the changes recommended to strengthen industry for a particular sphere of influence. These reports (typically with a title that includes *vision 2030*) have been prepared by individual countries, political sub-divisions like states and cities, various government collaborations, different strategic economic groups, various engineering societies, individual colleges, and other organizations [5] – [11] that are all reacting to the advent of an increasingly digital economy (i.e. the underlying issues driving Industry 4.0 or the IIoT). Lately, over the last year and a half, the American Society of Engineering Educators (ASEE) has taken up the challenge of reimagining how we should be educating our engineers and technicians across all disciplines. This multidisciplinary endeavor has been a joint effort involving both academia and industry and will culminate this phase of its activities in an Industry 4.0 Workforce Summit in the Spring of 2022 [12].

The Educational System:

For many years, the way that US higher education had been educating scientist, technicians, and engineers for manufacturing and other industrial sectors had remained fairly constant during the decades leading up to the Internet era. The curriculum model used followed a familiar pattern. In general, the first two years of a four-year engineering degree were spent studying math and science prerequisites and general education courses with the addition of several introductory courses in the major field of study. The last two years of the program dealt with the study of more advanced technical courses pertaining to the actual discipline one was enrolled in with only a few other elective courses that are not major centric. The resulting courses of study tended to be very theoretical versus practical in nature. This basic curriculum organization was in keeping with accreditation criteria from the engineering accreditation commission (EAC) of ABET and the technical courses within a degree program were fairly standard across the country with many courses at different institutions using the same popular textbook (i.e. a subject matter bible so to speak). Typically, four-year colleges were differentiated by their research faculty and graduate programs not their undergraduate degree programs. Beginning in the mid-1980s, the field of engineering education started to respond to numerous reports that there needed to be changes made to engineering education. An increased emphasis on synthesis and design, open-ended problem solving, development of management and communications skills, professional development, and career-long learning are all included in this call for change. This response was in reaction to a perceived need to correct a multiple decades long emphasis on engineering science that occurred post-World War II tilting the engineering education field away from engineering practice and the new realities of a global economy that demanded skill sets not emphasized at the time [13]. Several new initiatives drove changes in engineering education during the next several decades. Among these were ABET 2000 and *The Engineer of 2020: Visions of Engineering in the New Century*. The latter report was sponsored by the National Academy of Engineering and addressed the idea of the "knowledge economy" and the ability to be able to adapt to a constantly changing global economy [14]. At this point, the focus of this paper will transition to issues surrounding the two-year college domain and teaching the technicians of the future.

Since many two-year engineering technology programs were originally designed to supply support technicians for engineers in a particular field, much of what has been already stated about engineering education can be applied to engineering technology programs. For these programs, the curriculum is compressed into two years with several basic introductory technical courses offered in the first year and more advanced technical courses offered in the second year. Some programs were designed to be the first two years of a four-year program while some programs prepared their graduates for immediate entry into the job market. Again, within these two groupings, two-year programs in a certain technology field tended to be very similar to one another and would conform to the technology accreditation commission (TAC) of ABET criteria espoused at the time. These Associate (AS) Degree programs were more practical and hands-on oriented than the engineering programs with labs typically associated with each technical course. The era of the "engineering technician" started to decline as more and more two-year graduates were tasked with becoming field technicians that were required to maintain technical systems in the field or were involved with the manufacturing process and final test of products in an industrial environment (i.e. production technicians). In a manner similar to how four-year college programs reacted, the technical education community at the two-year college level started to embrace similar elements of the Scans report [15] (usually, problem solving skills and life-long learning) with efforts to infuse these so-called "soft skills" within the technology curriculum. In any case, during the period preceding the Internet age, both two-year engineering technology programs and four-year engineering programs tended to be islands unto themselves with little interaction with other fields of engineering or technology or the sciences. Since the start of the Internet era, two-year engineering technology education has been getting most of its direction and support from the National Science Foundation's (NSF) Advanced Technological Education (ATE) program that focuses on two-year college technical education [16]. Most of this support has been in the form of grants that fund projects or Resource Centers or Centers of Excellence that promote the dissemination of information about new technologies, provide faculty development opportunities, or introduce innovative teaching methods. One of the broad areas that the NSF emphasizes is advanced manufacturing at the two-year college level. As noted previously, the current ASEE Workforce 4.0 initiative also addresses two-year college technician education but not as expansively as four-year engineering education. Indeed, the recent Industry 4.0 Workforce Summit emphasized engineering versus technician education (personal communication with STCC Dean Lara Sharp, April 27, 2022).

Technology Convergences and the Challenge:

One might ask the question, what is different today that requires such a deep examination of our educational system entrusted with the development of future engineers and technicians? As mentioned before, there have been times when those involved with this educational endeavor have paused and questioned if the curriculum that was presently in place was serving those in the best possible way. To be sure, it seems like there has always tended to be an ongoing accretion of material that had to be included in a technical curriculum to keep up to date but the rate of technology change was not that rapid in most fields (with the exception of possibly the electronic and computer technology areas). The desire to add new material to a curriculum has led to many debates over what is still important and what has fallen out of relevance. But those debates were about a specific technology in a specific field and usually involved subject matter experts (SMEs) in that field to make the call. Most often, that just meant a new topic being added to a course or program. Over a long stretch of time, the result might be a new course as the lore of a particular new subject grew to merit its own status in the curriculum. Previously, as the rate of technology change started to accelerate with the advent of the integrated circuit (IC), the resultant evolution of technology was to some extent predictable by extension of the effect of Moore's Law [17]. Moore's Law (really an observation) predicted the growth rate of the possible number of transistors on a chip (IC) starting in the 1960s and it continues to be relevant today (six decades later!). This evolution of electronics has taken us from computers constructed from numerous large circuit boards plugged into back-planes, to single board computers, to systems on a chip (SOC) and has spun off innovations like micro-electromechanical systems (MEMS) and a host of other advanced technological inventions/innovations. It is this continued microminiaturization of electronics components that has brought us to where we are today [18]. As the role of the technician started to become more service oriented, the Scans report started to take center stage and soft skills started to drive the conversation about what was missing in the typical two-year college technology curriculum. This author was closely involved in the development and implementation of the New England *Verizon NextStep Program*. This long running initiative that educated then current Verizon linemen to become telecommunications technicians made the inclusion of soft skills a center piece of this industry sponsored program that led to an AS degree in Telecommunications Technology for several thousands of Verizon's employees [19, 20]. Certainly, the perceived acceleration of the pace of technology change was what gave rise to the call for life-long learning skills during the same time period. Another important driver of technician education during this era was the adoption of the PC as a technology tool. Besides its ability to afford access to productivity software (i.e. the Microsoft Office Suite, etc.) for the writing of reports or data gathering or display, many software simulation or graphics/drawing programs for specific technologies became available for use by technology students. Often, a course or two might be added to an engineering technology curriculum that applied the use of PCs and discipline specific software (CAD quickly comes to mind). One might also point to the introduction of the cellular telephone (wireless), and high-speed computer networking (digital communications) as technologies that were driving change in the landscape of technology and technical education at the close of the last century. Ultimately, the implementation of the world wide web and the networking system that would become known as the Internet arrived. Few, at the time, could predict how the PC and these new technologies would forever change how we live, work, learn, and play today.

The effect of Moore's Law continued to drive technologic change and the turn of a new century saw the proliferation of low-cost but powerful PCs with user friendly operating systems and browsers that could access the Internet, a new generation of cell phones with low-speed access to the Internet (but offering mobility to the user), and, most importantly, the construction of a country wide infrastructure that could support an ever-increasing data rate for Internet access through retro-fitted cable TV systems and existing telephone network copper pairs. The convergence of various digitally enabled technologies had given rise to the Internet age and the concept of the knowledge economy. Two decades have now past and we are again at another point of inflection with the convergence of technologies that again promise to revolutionize how we do things. Twenty more years of microminiaturization of ICs have increased PC processing power, given us inexpensive PC memory, flat screen high-resolution monitors and tablet devices, digital cameras and digital television, and a 5th generation of cellular telephones (i.e. smart phones) but most importantly to enable this new application of the Internet: low-cost powerful embedded microcontrollers, sophisticated sensor networks, and ubiquitous high-speed wired and wireless networking on a world-wide basis. The result of this technology evolution has put us deeply into the digital era and into the age of the Internet of Things or IoT. Many forecast that the emerging technology of the IoT combined with the nascent technology of machine learning (ML) and/or artificial intelligence (AI) has the very genuine potential to significantly impact almost every aspect of human endeavor and commerce by increasing system efficiency, reducing energy consumption, providing real-time monitoring of the nation's infrastructure and environment, and improving public health, educational opportunities, safety, and national security [21]. If one looks back at the uses of the Internet during the first decades of this century, one will likely conclude that the first generation of uses involved human centric applications (i.e. mobile and fixed personal communications, the ability to perform financial transactions, access goods and services, and avail ourselves to information, entertainment, and social media). Today, we can now use the Internet to enable sophisticated electronic control applications that were not previously possible. This new paradigm of Internet uses, machines talking to machines or M2M, will further change society in ways that we can only begin to speculate at this point in time. Futuristic applications like autonomous vehicles are now within the realm of reality, as are smart cities, smart agriculture, e-healthcare, and the list goes on. Novel IoT applications can be used to implement wide-spread and/or geographically large or small cyber-physical systems that link the physical world with the cyber world. These cyber-physical control systems have the ability to control complex electronic based systems in real time through low latency communication links. Again, this gives rise to control systems that heretofore were not possible but now can be used to improve the operation of industrial processes and systems from just about any field or sector.

So, let's articulate the problem facing higher education and in particular two-year college engineering technology programs. First, let's state that most believe that the rate of technological change has become exponential. This basic fact makes it all that more imperative that we act on educational changes that better prepare our students for the future. At the four-year engineering level, today's engineering students are not being educated in the emerging digital technologies that are transforming the workplace. Depending upon whom one asks there may be some variation in a list of these skills gaps, but in general they relate to the following engineering competencies: data science and advanced data analysis (i.e. big data), novel human-machine interfaces (HMIs), digital-to-physical interface technologies (i.e. 3D printing, additive manufacturing, etc.), data networks and digital communications and system automation, artificial intelligence and machine learning, robotics, programming skills, and IoT and cyber-physical systems technology [22]. These topics are basically a list of the various innovative digital technologies that can provide increased productivity, flexibility, and efficiency to an industry. If one does a Google search of scholarly articles about ASEE Industry 4.0, there is a substantial body of literature that is devoted to this topic by various educators at the four-year engineering level. In some cases, authors call for the inclusion of these digital technologies (some as required courses and some as electives) into the four-year mechanical engineering degree in a major (or radical) curriculum overhaul.

At the two-year technician level there are many manufacturing or “advanced manufacturing” programs along with programs that could be consider as manufacturing support technology programs such as electrical, electronics, industrial, mechatronics, and mechanical engineering technology. Furthermore, there are also computer networking, computer engineering, energy systems, and telecommunications technology programs which could also be considered to be secondary support technologies or all part of what may be considered “the advanced manufacturing technologies”. One might be inclined to attempt to address the perceived skills gaps due to the digital technologies listed earlier (for four-year programs) in present day manufacturing or advanced manufacturing two-year technology programs. However, there would be great resistance from these programs as their faculty would insist that their curriculum is already stretched to the breaking point and that their students don’t really need these skills. A glance at a typical manufacturing program’s curriculum would most likely verify the first belief but one might debate the second and as a result further speculate about the future needed skill sets of a technician in this field. With that as a backdrop, where do we go from here? Before that question is addressed, let’s look at some of the present two-year initiatives that are addressing skills gaps in manufacturing today.

Current Manufacturing Skills Gaps Efforts:

Today there are several NSF supported projects and Centers that are addressing skills gaps in the manufacturing industry. In the most recent ASEE Industry 4.0 webinar (Session #7, February 7, 2022) several of these entities took part in a panel discussion about what they could offer to other two-year college technology programs [23]. Taking part in the discussion were representatives from: the National Center for Next Generation Manufacturing, the Micro Nano Technology Education National Center, the National Center for Autonomous Technologies, the BEST Center, and The Future of Work, CORD with a lead-in presentation by Celeste Carter, Program Director, NSF. Of course, there are other NSF ATE projects that also address the manufacturing space. However, most of these projects or Centers are focused on addressing new technologies being employed in the manufacturing industry (hence, the term “advanced manufacturing”) not the implementation of digital technologies. Topics like additive manufacturing, micro-nano technologies, autonomous technologies, advanced digital literacy, and so forth, are areas typically packaged for two-year faculty professional development activities. If there is a systemic project to address the issues that have been outlined in this paper, this author is not aware of it. Of course, the reason for that has been touched on in the prior section of this paper. The present curricula of two-year manufacturing technology programs are already maxed out and it would seem to be more reasonable that the various manufacturing support technologies are the appropriate places were these skills gaps should be addressed. Since the digital technologies transforming the industrial processes are being embedded in the infrastructure of the systems they assist, the previously enumerated support technologies which tend to deal with the infrastructure of manufacturing should be the areas where the curriculum needs to be adjusted. To be sure there are other projects that are also attempting to address the changing nature of manufacturing. The MassBridge project [24] is a US Department of Defense (DoD) funded project from the DoD’s Manufacturing Technology Program [25]. This project is also limited in its scope and tends to deal with skills gaps caused by new manufacturing technologies (i.e. already mentioned, additive manufacturing, 3D printing, etc.) and a lack of skilled machinist, not gaps specifically caused by the digital economy. There is another very relevant NSF ATE project that addresses one particular aspect of the digital technologies’ skills issues, that being the technology of the Internet of Things. Many view IoT as the prominent hardware-based technology in the implementation of Industry 4.0 or IIoT. The *Internet of Things Education Project* (DUE1801090) has developed curriculum materials about IoT and its enabling technologies (i.e. embedded controllers, sensors networks, and wireless networking) and delivered both in person and online professional development experiences about it to two-year technology faculty. The project has also developed a one-year, 24-25 credit, *Internet of Things* certificate [26, 27] that is offered at Springfield Technical Community College in Springfield, Massachusetts. This certificate was designed with the goal of addressing the IoT aspect of the digital economy issue at the two-year college level. The IoT certificate courses are shown here [28]:

ELE-111 - Internet of Things (IoT)
ELE-111L - Lab: Internet of Things
CSE-150 - Linux Command and Shell Programming
CSE-160 - Intro to Programming Using Python
ELE-128 - Internet of Things Networking & Security
ELE-128L - Lab: IoT Networking & Security
CSO-105 - Cisco – Introduction to Networking
CSO-105L – Intro to Networking Lab

A student enrolled in this certificate must complete the required courses shown above and also take one course and the associated course lab from the following list:

BMT-230 – Bio-Medical Wireless Networking
BMT-230L – Bio-Medical Networking Lab
EET-135 – Programmable Logic Controller 1 (PLCs 1)
EET-135L – Lab: Programmable Logic Controller 1 (PLCs 1)

Also, a student enrolled in this certificate must also take one course (and the course lab if there is an associated lab) from the following list without duplication of the course and lab taken from the list above:

CSE-248 – Ethical Hacking
CSE-248L – Ethical Hacking Lab
CSE-172 – Cloud Computing for the Internet of Things (IoT)
ELE-168 – Developing the Things for the Internet of Things
ELE-168L – Developing the Things for the Internet of Things Lab
BMT-230 – Bio-Medical Wireless Networking
BMT-230L – Bio-Medical Networking Lab
EET-135 – Programmable Logic Controller 1 (PLCs 1)
EET-135L – Lab: Programmable Logic Controller 1 (PLCs 1)

Solutions:

As stated before, the curricula of most two-year manufacturing/mechanical technology programs are already bursting at the seams. It would seem, that the number of new courses needed to be added to the present curricula of these programs to bring a future graduate into the digital economy is unreasonable. However, a better approach is to ask the question is, "is it necessary?" Since the graduates of many of these programs go directly into the workplace, what is much more reasonable is the addition of a single introductory survey type course about the new digital technologies and overview details and examples about how they can benefit the manufacturing process or any other industrial activity for that matter. Actual exposure to these systems as they are implemented in the workplace would provide on-the-job training for present and future employees. Today, advanced manufacturing is supported by many other technicians that deal with the physical infrastructure of the manufacturing industry. Robotics and automation are typically dealt with by technicians that have gone through programs that teach those topics (i.e. two-year technical electrical/electronic/mechatronics programs). Networking, wireless digital communication technologies, and cyber-security tend to be the domain of computer networking technicians. However, the type of networking technician needed, needs to be an individual that is also knowledgeable about the operations technology used in the specific work environment as well as one familiar with basic IT applications. This author does not know of any two-year programs that presently produce networking technicians with these skills. The Cisco networking academy program has dipped a toe into these waters but what they provide the student with is very superficial in nature and would not provide the necessary context to be of much use in this author's humble opinion [29]. It would also seem that to achieve these skills one should already have a two-year degree in a particular field and then pick up the additional networking-oriented skills through additional training. The use of data science and big data to this point has been embedded in the business departments of the higher education world. These types of skills do not translate in a meaningful way to the various support technician technologies mentioned earlier. However, the collection of the data through data acquisition techniques does fit into the skill sets of the electronics-oriented support technicians. While the concepts and theory of IoT and cyber-physical systems technology presently really don't have a home, they could readily be added into the skill sets learned by the support technicians in the electrical/electronic/mechatronics fields. Programming and other computer skills (e.g. dealing with micro-controller interfacing) are routinely taught in technology programs that deal with robotics and automation so again these skills tend to be known by electrical/electronics/mechatronics leaning support technologies graduates.

Conclusions:

It is this author's contention that the best method to answer the challenge of Industry 4.0 and the IIoT is to take a multi-pronged approach to modifying two-year technical program curriculums. First, students that are studying manufacturing/mechanical technology at two-year colleges need to be exposed to the world of the digital economy and the emerging technologies that can be used to improve the industrial process – regardless of the industrial sector. A possible list of topics for this course could be as follows: Introduction to IoT and Cyber-Physical Systems, Microcontrollers and Sensors for IoT, Programming for IoT, Networking and Security Issues for IoT, Machine Learning and Artificial Intelligence, New Computing Technologies – Cloud, Edge, etc., Digital Twins, and New Computing Technologies [30]. Of course, depending upon a recent graduate's or incumbent worker's interest, some might want to return to school to pursue a certificate in IoT or networking or data science to change the focus of what they do in the industrial environment. The various electrical/electronic/mechatronic support technology students should be exposed to these topics (from the list above) with content from existing courses or new courses with enough rigor that they become familiar with the operation and implementation of IoT systems and the enabling technologies of IoT and cyber-physical systems. Of course, as expressed before, the best of both worlds would be the individual that graduated with a degree in a particular technical subject area (thus are familiar with the field's OT) and then returned to reskill themselves in the IoT technologies relevant to their chosen field. There are numerous other technology fields that will adopt these technologies into their operations. Some that come readily to mind are Building Automation (from the world of heating, ventilation, air conditioning and refrigeration or HVACR), smart and autonomous vehicles (not quite there yet), chemical/oil/material processing plants, smart city (civil) initiatives, and e-healthcare (medical applications). It would appear that we, two-year college educators, will be continually examining and upgrading the curricula of two-year technical programs that serve Industry 4.0 at an ever-increasing rate - it is also becoming imperative that the two-year college technology sector should be doing this in a more systemic fashion and with an increased sense of urgency.

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