



Developing the Industry 4.0 Workforce

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Abstract

This paper surveys the workforce development efforts for the fourth industrial revolution, known also as Industry 4.0. The paper sketches out the needs of the manufacturing industries based on the applications of Internet of things (IoT), cyber-physical systems concepts, and digital manufacturing, supported by multiple case studies. Individual courses specifically targeting Industry 4.0 have been gradually developed, however only a limited number of standalone programs are currently available since the area is very focused. Programmatic development efforts varying a wide range of educational and training backgrounds and levels are covered in this paper, including the MIT's Management Executive Education, practically oriented technical or engineering-based MS, BS, and AS degrees within the field in addition to the apprenticeship-based training programs including a one from the author's institution, and certification programs from industrial entities like Cisco. Each type and level program's contributions and their matches to the workforce needs are emphasized in this paper, along with the definitions of exact needs of the manufacturing industries. The paper is concluded with data on labor statistics, and programmatic and course-based development proposals to help fill current and future voids in workforce development. Minor- and concentration-based program designs are highlighted for complementing existing ABET accredited programs in electrical and computer engineering, manufacturing engineering, and engineering technology.

Background

Until recently, manufacturing industries has been lacking skilled workers including welders, CNC programmers and machinists. However, with the start of Industry 4.0 or the 4th industrial revolutions, the lack in skilled workers will have additional burdens added to it. Like every new technology, new type of jobs are being created requiring new skill sets, hopefully not displacing the existing workers but reinventing their work. *According to the some reports, between 75 to 375 million workers worldwide will have to change their occupational categories due to sizeable amount of work being automated or computerized by 2030* [1][2][3].

According to the manufacturing experts collaborative robots, industrial Internet of things (IIoT), data analytics, machine learning, and digital twins will make manufacturing safer, more efficient, and productive [4]. To address the needs of Industry 4.0 workforce, companies need to retain, retool of the existing skilled workforce, and recruit a new one, possibly from the high school ranks as they enter the engineering education. Training is required anywhere from executives' need of understanding the nature and power of Industry 4.0, to preparing engineers who design and help build, and technicians who build and maintain the infrastructure, along with data analysts/computer scientists dealing with big data and AI applications.

Industry 4.0 Education

The following section details the results of the literature review targeting existing Industry 4.0 programs in the U.S. *Small number of existing programs directly targeting the Industry 4.0 workforce development, mainly in the Internet of Things (IoT) were found. All of the programs found are fairly new (established since 2017) and are in Computer Science/Engineering and Electrical Engineering departments. No such program was found in Manufacturing and Mechanical Engineering departments.* This paper, after presenting study of the existing programs, will propose a similar program for Manufacturing/Industrial or Mechanical Engineering disciplines.

Programs targeting Industry 4.0 can be categorized *at different levels, varying through executive education, graduate/BS/AS degrees, and work-force training programs. ONLINE format is also common due to the heavy presence of IoT content.*

- **Executive Education:** MIT has been offering an IoT course a part of their management executive education program, entitled “Business Implications and Opportunities of IoT”. [3]. In this self-paced Online training, if an individual spends 6-8 hours/week, he or she can complete the course in 6 weeks. The motto for the course is “IoT is not a technology, it is a leadership opportunity; a mechanism to transform businesses.”. The course aims to help executives envision/lead IoT-based transformations – by achieving strategic advantage IoT drives. In addition, the course provides [5]:
 - “Introduction to the IoT technologies, skill components, enablers and constraints for using IoT in business”.
 - “Examples where IoT is already transforming customer experience, operations and business models”
 - “Explains the elements of leadership capability that makes transformation possible.”
 - “Real-world case studies, senior executive interviews, self-assessments and practical assignments guide the participants as they construct a roadmap to gain strategic advantage from IoT”.
- **Graduate Degrees:** University of New Mexico (UNM) Online has been offering an MS degree in Computer Engineering with a specialization in IoT [6]:
 - The program is consisted of 31 credits of 8 week long courses. The curriculum has good IoT content relevant to computer engineering. However, only one course is labeled with IoT in its title.
 - “Students will learn how to develop the software and hardware systems that allow devices to collect and exchange data on a massive scale”.
 - Students who successfully complete the curriculum will be prepared for entry into the computer industry or related fields of study such as autonomous and electric vehicles, smart grid, situational awareness for smart health, crowdsourcing based services, and security for smart cities.”
 - The program encompasses the following courses shown in Figure 1:

UNM Online MS in CE - IoT

<ul style="list-style-type: none"> • Required Courses (13 credit hours): • ECE 517 Machine Learning • ECE 531 Introduction to Internet of Things • ECE 537 Foundations of Computing • ECE 540 Advanced Networking • ECE 590 Graduate Seminar (1) 	<ul style="list-style-type: none"> • Additional Elective Courses (18 credit hours): • ECE 439 Introduction to Digital Signal Processing • ECE 514 Nonlinear and Adaptive Control • ECE 522 Hardware-Software <u>Codesign</u> with FPGA's • ECE 525 Hardware-Oriented Security and Trust • ECE 529 Introduction to Cybersecurity • ECE 530 Introduction to Cloud Computing • ECE 535 Satellite Communications • ECE 595 ST: Stochastic Processes (1.5) • ECE 595 ST: Optimal Estimation and Filtering (1.5) • ECE 595 ST: Cybersecurity II • ECE 595 ST: Radiation Effects on Electronics
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Figure 1. UNM Online MS in CE with a specialty in IoT [6]

- **BS Degrees:** Florida International University (FIU) Online has been offering a 120 credit Online BS Internet of Things degree since 2017 [7]. Make up of the program is given below:
 - General Education/Mathematics & Science Courses (60-61 credits)
 - IoT Core Courses (49-50 credits)
 - Computer Science/Electrical Engineering/Computer Engineering Electives (10 credits)
 - The program is a standalone one which is similar to electrical and computer engineering preparation with a concentration/specialty in IoT.
 - The program is a practically oriented technology type of curriculum due to lack of higher level math and having non-calculus based physics.
 - The details are the curriculum are given in Figures 2, 3, 4, and 5.

FIU Online BS in IoT

<ul style="list-style-type: none"> • General Education/Mathematics & Science Courses (60–61 credits): • SLS 1501 First Year Experience (1) • ENC 1101 Writing and Rhetoric I • ENC 1102 Writing and Rhetoric II • Humanity G1 – Suggested HUM 1020 Introduction to Humanities • Humanity G2 – Suggested AFH 2000 African Civilizations • Social Science G1 - SYG 2000 Introduction to Sociology • Social Science G2 - LBS 3001 Introduction to Labor Studies • Art – Suggested COM 3404 Nonverbal Communication • Electives – ELE UCC1 (19 credits) 	<ul style="list-style-type: none"> • Math 1 – MAC 1105 College Algebra • Math 2- MAC 1114 Trigonometry • Science 1 – PHY 2053 Physics without Calculus I (4) • Science 1 – PHY 2048L General Physics I Lab (1) • Science 2 – PHY 2054 Physics without Calculus II (4) • Science 1 – PHY 2049L General Physics I Lab (1) • COP 2250 Java Programming
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Figure 2. FIU Online BS in IoT – Gen Ed. Mathematics and Science Requirements [7]



Figure 3. FIU BS Online in IoT – IoT core courses [7]

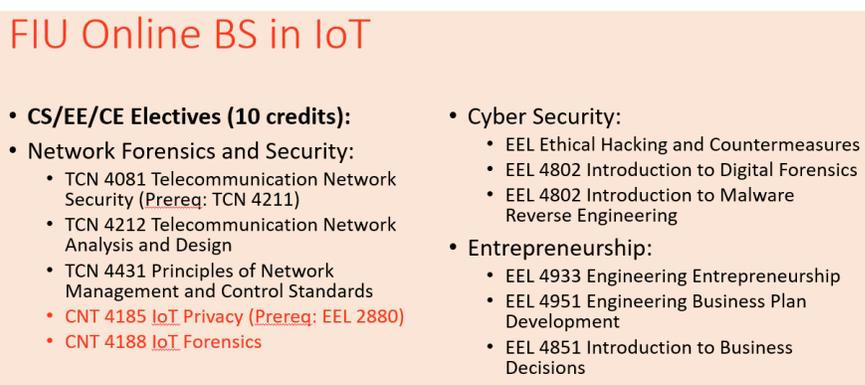


Figure 4. FIU BS Online in IoT – CS/EE/CE electives [7]



Figure 5. FIU BS Online in IoT – CS/EE/CE electives [7]

In addition, the Devry University is offering a BS degree in Mobile and Networked Devices encompassing concepts and techniques to navigate information technology and mobility, networked devices and embedded systems, the ecosystem of the IoT, and information security and mobile devices. [6]

- **Associate Degrees:** Miami Dade College (MDC) started offering a 60 credit AS degree in IoT Applications in 2018 [8]. The college seeks to fill in the positions requiring IoT

skills to develop, deploy and support connected devices. The program prepare graduates for career opportunities like:

- IoT programmer, IoT developer, IoT consultant
- Product application assistant, rapid prototyping assistant
- Connected devices support specialist
- Embedded software developer, embedded application programmer
- The curriculum for the program is given below in Figure 5 and 6. 8 credits in total in electives has the IoT name embedded in a course title. [8]

Figure 6. MDC AS in IoT – Gen Ed requirements [8]

Figure 7. MDC AS in IoT – major course requirements and electives [8]

- **Workforce Training Programs:** The Miami Dade College is also offering a 24 credit certificate similar to their AS degree. [9] Multiple industrial entities are also picking up the slack, with the Cisco Learning Network offering multiple IoT certifications [10], and SME’s Tooling U. addressing some of the new skill gaps. [10] And most importantly, the Microsoft has been offering an IoT school with a Azure IoT developer boot camp with 10 modules in 7 hours and 33 minutes length in addition to providing an IoT hub, a fully managed service and Azure IoT SDKs and developer tools including 3 modules in 2 hours and 7 minutes length. [12]. Coursera is also offering a multiple course bundle focusing on programming the IoT [12] through Arduino and Rasberry Pi hardware and Python Programming through the University of California – Irvine.

Analysis and Conclusion

According to the job resources, IoT workforce need will grow by 50% within a couple of years. [1]. At this stage, Industry 4.0/IoT training needs are being addressed by a wide range of efforts, varying from executive education to workforce training. Manufacturers are engaging public private partnerships in development of standard skill certifications and advanced manufacturing career pathways. [13]

However, the number of academic programs directly targeting IoT is very small. Those few started since 2017. Growing number of EE, CE, or ECE programs are also offering at least one course in IoT design and applications. Most of the development efforts are focused on professional and career development types in technologist and technician programs including the examples given above such as FIU, Devry, Miami Dade College.

As a conclusion, there will soon be a large void in the IoT workforce as it seen from the number of current programs and courses available. This critical void needs to addressed at all levels from executives to technicians. Minors and concentrations in different engineering and technology disciplines can help remedy this problem. IoT related hardware including sensors and networking equipment, programming, and information and networking security relevant courses and programs need to be developed *along with the missing Industry 4.0 components on digital manufacturing, digital engineering subjects including digital twins and business analytics with big data, machine learning and artificial intelligence.*

Future Work

Role of manufacturing/industrial and mechanical engineering programs are critical in helping supply Industry 4.0 trained personnel for U.S. manufacturing industries, beyond the IoT focus of CS/CE/EE programs. Table 1. summarizes the IoT-based mandatory courses (junior to senior level) which can be offered in manufacturing/industrial and mechanical engineering undergraduate programs. These can be offered as a part of a minor or a concentration:

Mandatory Course (3 – 4 credits)	Details
Introduction to IoT and Cyber Physical Systems (Junior) (3)	An introductory course using Arduino-based kits and simple laboratories, assuming that the students took a general programming course and some electrical/electronics content.
Microcontrollers and Sensors for IoT (Junior/Senior) (4)	Building on the first course, this course will focus on the hardware being utilized in IoT applications.
Programming for IoT (Junior/Senior) (4)	Also building on the first course, this course content will include programming for data acquisition, storage/sharing, and analytics.
Networking and Security Subjects in IoT (Senior) (4)	Taken after the second and third course above, the course will give basic knowledge of networking as it relates to IoT including wireless communications, and security subjects.

Table 1. Possible IoT curriculum

Multiple other Industry 4.0 courses (Table 2) can be designed to added to the IoT mandatory curriculum above to enhance the IoT experience, requiring possibly additional preparation through prerequisites outside the curriculum given.

Elective Courses (3 -4 credits)	Details
Machine Learning and Business Analytics (Senior/possibly MS) (4)	Programming course above and possibly one additional preparatory course in business analytics can be used as a pre-req. for this course.
New Computing Technologies (Senior/possibly MS) (4)	Edge and cloud computing, possible use of Amazon Web Services (AWS)
Digital Twins (Senior/possibly MS)	Will focus on understanding and use of digital twins in machine and product design life cycles. Will require strong IoT and CAE knowledge.
Mixed Reality for IoT (Senior)	Use of Augmented and Virtual Reality in Industrial Applications.

Table 2. Elective courses (some of the courses can possibly be used in MS programs)

The course given in Table 2 can elevate the IoT programs to a *more comprehensive Industry 4.0 level*. Additional improvements can be coming from *Digital Manufacturing* subjects such as 3D scanning and printing, CAD/CAE,/CAM/CIM and their interfacing with the cyber-word.

The author has been developing two interdisciplinary courses, one in Introduction to IoT (Table 1) and another in Mixed Reality for IoT (Table 2) based on their previous work in the field. He also studied the digital twin area through case studies for possible research work and course development recently. A third course focusing on Digital Twins is being also planned for development. Even though the digital twin concept was coined 2010, most known work happened very recently [14]. Developing a course in these areas is a challenge but also accelerates applications development for manufacturing industries, with new concepts becoming available every day.

In addition, the author is a part of the new ARM (Advanced Robotics for Manufacturing Institute located at Carnegie Mellon University) effort for its Asset Management System (AMS) development to connect the job seekers and employers with the educational and training opportunities, and jobs in Industry 4.0, especially in advanced robotics. The effort will soon yield a survey to identify the critical competencies for relevant positions as well as the availability of work-force development opportunities.

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