Future of Engineering Education: Cyber Physical Systems Engineering

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Abstract Recent Industry 4.0 developments have created disruptive changes in industries. It has also changed the way people work and the required skills of workforce for the future. This new technological advencement has created requirement of workforce combining information technology (IT) and production knowedge. Unfortunately, many schools and universities have still been training students behind Industry 4.0 developments and requirements. Therefore, it is important to understand what characteristics and knowledge as well as skills are required for the future of jobs and engineering profiles to shape the new education requirements. This paper aims to address the future of engineering education specifically by focusing on a promising engineering department that is the cyber-physical systems (CPS) engineering. We also aim to discuss how the curriculum of that novel discipline, CPS engineering, should be for the future of engineering requirements.

Keywords CPS engineering • engineering education • future of education • cyber physical systems engineering • Industry 4.0

Introduction

Fourth industrial revolution includes an integration of advance automation in factories to create smart process environment. To carry out an efficient production, all machinery and equipment in production environment are coordinated through the Internet with the help of sensors and all required data with the cloud storage. Ka-

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germann et al. (2013) defines Industry 4.0 as the evolution of technology from embedded systems to cyber-physical systems (CPSs). By the help of embedded systems, IoT, MtoM communication and CPS technologies, it is possible to integrate the virtual environment with the physical world. By the result of that smart factories are emerging to overcome the complexity of the production environment (Xu et al. 2018). Researches also illustrate the importance of Information and Communication Technologies (ICTs) as well as embedded systems, IoT, CPS, Industrial Integration and Industrial Information Integration in the infrastructure of tomorrow's smart factories.

The first three industrial revolutions are the result of mechanisation, electricity and IT. Industry 4.0 is a result of the introduction of the IoT into the manufacturing environment. In the future, industries are estimated to have global networks incorporating a CPS oriented machinery and production facilities. By the help of CPSs, smart machines and production inputs will be able to exchange information, make decisions and control systems, inteligently. Hence, significant improvements in industrial processes, material usage and supply chain management as well as life cycle management are expected results of Industry 4.0. By the creation of smart factories, there will be smart products speading all over the facilities, running all the times and, keeping their own history, tracking data and current status and alternative routes to achieve a pre-defined target. By also vertically and horizontally networked processes in manufacturing environments and facilities, these smart products will enable the inteligently managing of the industries.

Evolution towards smart environment in industries has changed the future of required workforce structure. According to the 2019 World Development Report (World Development Report 2019), due to the recent technological developments, while some kinds of jobs are being eliminated, some others are created and some others are altered. It is suggested for companies that in order to remain competitive and to keep pace with it, they should invest capital more in human and adapt their employee by training them to gain the required skills. For instance, in the 2019 World Development Report (World Development Report 2019) a new trend in employment strategy in companies is declared to be a flexible employment strategy aligning with companies' needs.

For those future of the changing workforce requirements, and the CPSs jobs of the future, some of hot topics have emerged. These are: artificial intelligence (AI), programming, software engineering, autonomy, statistics, computation, automation, complex and integrated systems. These topics are also to diffuse in the engineering higher education curricula. Thus, engineering faculties should rethink and renovate their education curricula by integrating novel hot trends towards Industry 4.0 developments. In this paper, our aim is to shed a light on a novel engineering discipline, CPS engineering curricula promising to grow in a near future. We researched on the subject and summarized our findings in the following sections.

Literature Review

We summarize the literature works on how jobs change and new requirements emerge in workforce structure. According to the Rockefeller Foundation's one of surveys (2017), in their professional lives, almost half of recent college graduates do not use the skills they gained during their college education. 86 percent declare that they learn new skills outside of college.

According to Long et al. (2019), engineering education requires different design concept than science education. For instance, engineering education includes designing and building things. Therefore, it must be up-to date in terms of techniques, technologies, and trends. They also declare that four-year education period is a very short time period for engineering education. Therefore, the curricula of engineering education should be designed carefully with the relevant topics for the 21st century.

Susskind and Susskind (2016) declares an estimation that within 20 years 50% of US jobs could be automated. Frey and Osborne (2013) also estimates a similar automation replacement prediction for future. According to them, some of professional jobs such as doctors, lawyers, teachers, etc. will dramatically change. However, jobs cannot be automated will mostly involve the skills such as complex communications, analytical thinking, creativity, perception and adaptability, etc.

It is well known that the U.S. universities have good reputation in engineering education. However, according to a recent report by News and World Report (2020), Tsinghua University is ranked number one in top ten six Asian universities. For instance, in Computer Science discipline, Tsinghua is ranked as number one, and two other Chinese universities are ranked in top ten. This ranking of Tsinghua University is above of the well known US universities such as Carnegie-Mellon, Princeton, Georgia Tech, Cambridge, Oxford, Illinois, Michigan, and Caltech, etc. That ranking work includes 28 subjects in the sorting process. According to the McKinsey Global Institute's latest report (McKinsey Global Institute Report 2017), it is evaluated that jobs such as computer scientists, engineers, and IT administrators which are related to developing and deploying new technologies are expected to grow by 2030.

According to Linkedn's 2018 U.S. Emerging Jobs Report (2018), 2018's top five emerging jobs are: block chain developer, machine learning engineer, assurance staff, and sales development representative.

Brynjolfsson and McAfee (2016) state that: "Not only are the new technologies exponential, digital, and combinatorial, but most of the gains are still ahead of us. In the next twenty-four months, the planet will add more computer power than it did in all previous history. Over the next twenty-four years, the increase will likely be over a thousand-fold."

Another future of job alert is given by the White House, USA. In the AI Report (2016), it is metioned significantly on the need for Americans to be educated and trained towards software and AI-related subjects.

Zivi (2017) presents a work on one of the unique practical CPS education on the U.S. Naval Academy's Cyber Science education curriculum. He gives information how a CPS education should be in terms of the contents.

Ekren and Kumar (2020) have studied the future of engineering education by focusing on Industrial 4.0 revolution. They summarize the findings on what future of higher education would look like in the near future.

It is obvious that IT is changing at an exponential rate. Hence, there will not be enough space to retrain students after they graduate. Namely, if students graduate from universities weakly, they may never catch up the 21st century requirements due to that rapid changing world. Hence, engineering faculties should focus on renovating the engineering curricula towards novel requirements and developments. In this paper, we propose a trending engineering education towards Industry 4.0 developments that is CPS engineering by investigating how the curricula should be configured to meet the future of work requirements. We investigated the universities' related curricula and current projects progressing on this related subject, and summarized our findings.

Areas Related with CPS Engineering

In USA, a multiyear NSF funded project pursued by the National Academies of Sciences, Engineering, and Medicine focuses on developing and addressing effective CPS education (CPS Education Report, 2016). In that report, it is declared that the future of CPS workforce is likely to include a combination of engineers in the fields of computer science, mechanical engineering, systems engineering, and electrical & computing engineering. The report summarizes the related areas of the CPSs as:

- ***Robotics***: It is an interdisciplinary branch in engineering and science including mechanical engineering, electrical and electronics engineering, information engineering, computer science, and other disciplines. This area studies systems with sensors and actuators operating autonomously or semi-autonomously in cooperation with humans. Robotics include the topics of kinematics, dynamics, robot hardware and control software; perception, sensing, and state estimation; as well as control of manipulators and vehicles. Although many robots are often considered to be CPS, many CPS are not considered as robots. In robotics program, particularly some of the subjects particularly cover that field.

- ***Systems engineering*****:** It is an interdisciplinary field of engineering and engineering management focusing on how to design and manage complex systems over their life cycles. This area contributes significantly to CPS due to complexity of environment with the recent highly connected systems. Systems engineers typically focus on the efficiently management of integrated large complex systems. However, they do not usually address the detailed technological requirements of the cyber aspects of systems.

• ***The Internet of Things (IoT)*****:** This subject is a system component composed of computing, mechanical and digital devices, objects, people etc. It has the ability of transfering data over a network associated with users and their environments. With the recent advancements, the IoT applications require CPS characteristics such as real-time control, real-time response, etc. For instance, smart city implementations require IoT applications and in a sophisticated CPS environment.

• *The Industrial Internet*: It includes interconnected sensors, devices, and other instruments which are also connected with other industrial applications. By this connection, data collection and exchange as well as its smart analysis would be possible. Thus, productivity and efficiency would increase as well as other economical benefits can be acomplished.

Mainly by focusing on the above four main CPS related subjects, we draw the future of CPS Engineering Education curriculum below, also with the help of current curricula at some universities as well as reports of projects (CPS Education Report, 2016).

A CPS Engineering Education

In the era of Industry 4.0, "smart things," industries are eager to implement CPS. To be able to correctly design, invent, build, and deploy these systems, interdisciplinary skillsets are declared to be significantly necessary than ever before. In the CPS Education Report (2016), it is declared that by computing and engineering related disciplines, realization of CPS environment would be possible. It is also mentioned that the requirement of expert knowledge on CPS is significant. We summarize our findings on CPS Engineering Education by also considering that report, in this paper.

In the CPS Education Report (2016), it is also declared that designing a CPS course or degree program would involve a careful balancing of physical and cyber aspects and application knowledge. To develop the CPS curricula, the report includes model curricula from multiple perspectives (CPS Education Report, 2016). The report identifies six overarching foundations. They are described in the following sections.

Foundation 1: Basic concepts for computing

It is declared that a CPS expert cannot become sufficient by solely one or two programming courses. It also requires solid training in computing such as: data structures and algorithms; programming; computation models, embedded hardware; discrete event models; model-based design; real-time tracking systems; and network programming.

Foundation 2: Physical world computing

For the CPS education, the requirement of computing foundations with physical-world properties and constraints should be emphasized. Real-world comprises of complex systems. It is hard to anticipate the complexity of the system by the system designers and by a software. Therefore, the first step for students is to thoroughly understand the sensor concept, actuators and their programming, signal analysis, realtime control of systems, embedded systems, resource management, constraint management for time, memory size, and power, as well as techniques for defeating unreliability in practice.

Foundation 3: Discrete and continuous mathematics

It is declared that both discrete and continuous mathematics are foundational skills for all CPS engineers. Hence, it is significant for students to learn how to integrate these techniques with the real systems. Besides the mathematics, students will also require to understand graph theory, combinatorics, probability and statistics, stochastic processes, logic, linear algebra, calculus and differential equations, etc.

Foundation 4: Cross-cutting application of sensing, control, communication, actuation, and computing

The report declares that Foundation 4 is significant due to the cross-cutting nature of CPS, and communication networks and sensing, signal processing, and actuation with real-time constraints. Hence, the curriculum should be designed with an interdisciplinary concept. At the core of this foundation, there is knowledge of control, signal processing, embedded system design and their implementations. To detail, the below issues are suggested to be covered in the CPS curricula (CPS Education Report, 2016):

- Linear and nonlinear system control algorithms, stochastic processes, adaptive and hybrid control, and system identification;
- Optimization as well as optimal control of dynamic systems;
- Real-time analysis, control theory, and decision-making under noisy data condition (data-driven models);
- Wireless, synchronous and asynchronous communications, and ad hoc networking;
- Software requirements based on physical characteristics;
- Control-based signal processing, network management, models for computation and communication;
- Safe and reliable system, and dependability;
- Secure and private systems;
- Human factors related aspects;

Foundation 5: Control, computing, and communication of heterogeneous and dynamic systems

This foundation requires control, communications, and computing subjects. The relevant topics are: linear, nonlinear, and dicrete-event modelling, hybrid models, optimization, dynamic programming, probability and stochastic modelling, etc. Key concepts also, include uncertainty and risk; properties of physical world and computational devices; communication of systems (e.g., wireless communications); error detection and correction; merge of physical and computational models; and analysis and integration of signals and systems and finite-state automata.

Foundation 6: System development for CPS

Initial requirements for system development are: certification of safety-critical systems, resiliency, and high confidence, etc. Through it, students are suggested mastering these key concepts: safety, resilience, security, privacy, assurance cases, threat analysis, verification & validation, system design, Internet of Things, cloud computing, testing, etc.

In the report a sample of a bachelor's degree CPS engineering curriculum is also provided (see, Figure 1). From that curriculum, it canbe observed that the CPS programs include both computer science and electrical engineering programs related courses. It is also mentioned that, the difference in CPS curricula would be due to whether the program mostly focuses on a computer science or an electric and computer engineering perspective.

One Model for 4-Year, 40-Course Undergraduate Degree in CPS

Math and Natural Science (10 courses)

- Calculus I and II
- Differential Equations
- Linear Algebra
- Probability and Statistics
- Logic
- Physics I (Mechanics and Dynamics)
- Physics II (Electrical Circuits)
- Chemistry or Biology
- Discrete Math

CPS Core (12 courses)

- Introduction to CPS (Freshman Laboratory Course)
- Computer Programming
- Data Structures and Algorithms
- Programming Physical Systems
- Software Engineering
- Model-Based System Design
- Heterogeneous Models of Computation
- Formal Methods and Synthesis
- Resource-Aware Real-Time Computing
- Control Systems
- Optimization
- Digital Signal Processing

Fig 1. A 4-yer undergraduate degree curriculum for CPS engineering (source: CPS Education Report, 2016)

Current Bachelor Degree Curricula in CPS Engineering

We searched the current bachelor degree cycber-physical systems engineering related departments at colleges and universities in the world. We found that there exist mostly graduate levels in this discipline. However, two of schools, U.S. Naval Academy and Depaul University in the US provide a related bachelor degree program at their schools. The curriculum details are given for Naval Academy and Depaul University by Figure 2 and Figure 3, respectively. In Figure 2, only the cyber science related courses except the other core courses are summarized. In Figure 3, the whole curriculum for the CPS Engineering program is provided.

Although currently we could only find two bachelor degree programs in the CPS engineering, due to the recent Industry 4.0 developments, it would be promising to grow in the near future. Since the programs could be shaped towards either more electrical engineering, or software engineering, or systems engineering, students could select the program and the universities depending on their choices. Therefore, while shaping the program curriculum, the university first shoud decide what qualified graduates it is aming to give after its education.

U.S. Naval Academy
Cyber Science Courses

Cyber Security I
Cyber Fundamentals I
Cyber Systems Engineering
Systems Programming & OS Fundamentals
Data Structures for Cyber Operations
Applied Cyber Systems Architecture
Information Operations, Social Engineering, and Hacktivism
Web & Database Cyber Operations
Security: Fundamental Principles
Networking & Mobile Computing
Cyber Operations I
Cyber Operations II
Cyber Planning & Policy
Cyber Law & Ethics

Fig 2. Department of cyber-science curriculum of U.S. Naval Academy

DePaul University
Cyber Physical Systems Engineering

Introduction to Computer Science I	University Physics II
Introduction to Computer Science II	University Physics III
or	Probability and Statistics I
Python for Programmers and 1 Major Elective	Networking for Cyber-Physical Systems
Data Structures I	Cyber-Physical Systems Engineering I
Discrete Mathematics I	Cyber-Physical Systems Engineering II
Discrete Mathematics II	Cyber-Physical Systems Engineering III
Calculus I	Embedded Systems I
Calculus III	Embedded Systems II
Calculus III	Cyber-Physical System Security
Data Structures II	1 Major elective
Design and Analysis of Algorithms	Linear Systems
Computer Systems I	Foundations of Cyber-Physical Computing
Computer Systems II	Cyber-Physical Systems Engineering Practicum I (Experiential Learning)
Multivariable Calculus I	Cyber-Physical Systems Engineering Practicum II (Capstone)
Linear Algebra	Technical Writing
Differential Equations	3 Major electives
University Physics I	1 open elective

Fig 3. Department of cyber-physical systems engineering curriculum of DePaul University

Conclusion

This paper aims to study the future of engineering education specifically by focusing on a promising engineering department, cyber-physical systems (CPS) engineering. We also discuss how the curriculum of this novel discipline, CPS engineering, should be in order to meet the future of engineering requirements. After providing the required information for understanding the CPS discipline properly, we provide two current curricula form this program from different universities. Besides, we also present an NSF funded project's work by providing a developed curriculum for the program.

As a future work, this study can be extended in many directions. For instance, one may focus on a specific curricula in CPS engineering by considering some expertise classes under the program. Namely, first those expertise classes (e.g., software, electrical, systems engineering oriented, etc.) could be defined under the CPS engineering and then, specific curricula for those classes can be proposed followingly. Besides, the other current engineering disciplines such as industrial engineering, computer science, etc. could be investigated under a CPS environment. How those current departments' curricula should be renovated towards CPS environment would also be a promising work as a future study.

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