Curricular Excursions on the Internet of Everything

John Impagliazzo[1](✉), Natalie Kiesler[2], and Juan Chen[3]

[1] Hofstra University, Hempstead, NY, USA
john.impagliazzo@hofstra.edu
[2] DIPF Leibniz Institute for Research and Information in Education, Frankfurt am Main, Germany
kiesler@dipf.de
[3] National University of Defense Technology, Changsha, Hunan, China
juanchen@nudt.edu.cn

Abstract. Including dispositions and skills in computing curricula is beginning to take root in education circles. These two dimensions complement the knowledge dimension to form an understanding of competency taken in context. In a parallel movement, the Internet of Everything (IoE) is an emerging area of learning that focuses on the interaction between people and machines (things) involving data and processes on the internet. It is time, therefore, to channel student studies toward a competency-based IoE curriculum. This work attempts to initiate a discussion on this goal by proposing a "Draft 0" curriculum on the IoE that reflects competency, where students prepare to enter the workplace upon graduation. The proposed curriculum intends to stimulate discussion and garner more significant insight into developing a competency-based study plan on the Internet of Everything.

Keywords: Internet of Everything · IoE · computing education · computing curricula

1 Introduction

Dispositions, skills, and knowledge taken in context form the three competency components. Recent curricula recommendations, like the IT2017 [21] and CC2020 [1] reports, highlight the importance of transitioning from a knowledge-based educational setting to competency-based education. In addition, global industries and businesses seek computing and engineering graduates that are adaptable, collaborative, inventive, meticulous, passionate, proactive, professional, purpose-driven, responsible, responsive, and self-directed [9]. These eleven defined competency dispositions appear in the CC2020 report. Table 1 describes a listing containing the meaning of these dispositions.

Studies have shown that dispositions are necessary for a successful career [3]. It would seem unimaginable to think that industrial and governmental institu-

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Table 1. CC2020 Dispositions

Disposition	Elaboration
Adaptable	Flexible; agile, adjust in response to change
Collaborative	Team player, willing to work with others
Inventive	Exploratory, look beyond simple solutions
Meticulous	Attentive to detail; thoroughness, accurate
Passionate	Conviction, strong commitment, compelling
Proactive	With initiative, self-starter, independent
Professional	Professionalism, discretion, ethics, astute
Purpose-driven	Goal-driven, achieve goals, business acumen
Responsible	Use judgment, discretion, act appropriately
Responsive	Respectful; react quickly and positively
Self-directed	Self-motivated, determination, independent

tions would only accept a graduate with some of these eleven attributes. Therefore, computing and engineering educational programs should address dispositions fully in their teaching, learning, and assessing approaches. Doing so could help their placement practices. Since only 5% of graduates continue to graduate school [17], 95% of the graduates of such programs must possess these eleven elements in various levels of achievement as they enter the workplace.

In this work-in-progress paper, the authors examine current industry expectations toward graduates who seek to apply for the Internet of Everything (IoE) or related positions. The goal is to begin a conversation by proposing an IoE curriculum and associated competencies that could benefit learners seeking the equivalent of an IoE specialty or degree. It also explores the IoE implications for computing education.

The IoE area is relatively new, starting about a dozen years ago. The 2023 IoECon website describes the Internet of Everything as follows.

> *The internet of everything has four essential components: things, people, data, and processes. Things consist of machines, devices, and sensors that form the fundamental objects of the IoE ecosystem. People provide the intellectual basis of the IoE since humans analyze data and create essential insights from operations. Data form another IoE component, whose content increases each year exponentially and whose management becomes increasingly complex. Process is the fourth IoE component that determines how each of the other three elements provides increased digital value by transferring data to the right person or device* [4].

In short, the IoE may be defined as "a distributed network of connections between people, smart things, processes, and data, whereas these components interact and exchange real-time data" [10].

As with all new fields, it is difficult to recommend what students must learn and know, and how to perform in the workplace. However, describing a study plan for IoE in the context of competency only provides a first step in achieving study recommendations for the emerging discipline.

Given this description, indicating some information related to IoT education is beneficial. As with other areas of computing and engineering, a community of educators emerges to address how community members can participate in improving the entity at hand. This community often establishes organizations and related conferences to promote community attributes and debate challenges. In addition, such entities often have curricular recommendations for topic or course enhancement and even recommended degree programs. The authors present a "Draft0" for a possible curriculum for the Internet of Everything.

The objectives of this work-in-progress are to (a) develop a minimal curriculum for IoE students seeking an undergraduate degree, (b) identify which competency elements might accompany curricular recommendations, and (c) describe what computing and engineering educators can do to promote competency in an undergraduate IoE curriculum. This preliminary study builds on methods already used in professional disciplines and describes some principles to attract competent IoE graduates into industry and government.

2 Background

The ACM/IEEE Computing Curricula 2020 (CC2020) report recommended that university programs focus on competency-based learning instead of knowledge-based learning. This approach changes the way computing educators should teach and evaluate students. From the IT2017 and the CC2020 reports, professional competency from an academic perspective is:

$$Competency = Knowledge + Skills + Dispositions$$

in the context of performing a task. However, this same concept, from an industry perspective, would likely take this form:

$$Competency = Dispositions + Skills + Knowledge$$

in the context of performing a task. Although equivalent to the first version, this second version emphasizes dispositions and skills, followed by knowledge.

Having the proper dispositions and skills means the person hired fits into the workplace with the expected characteristics and must then be able to perform on the job with little attention to the person's knowledge background. Therefore, having the requisite knowledge to support dispositions and skills becomes an advantage in the workplace. Hence, this study will emphasize a "performance first" approach for an IoE curriculum.

The emergence of the Internet of Everything with the elements of competency in computing education suggests competency in IoE studies. Competency is essential to IoE education because an IoE student and graduate should be able to “fit” into the workplace. Such a graduate should have a diverse background with skills needed for people-to-people (P2P), people-to-machine (P2M), and machine-to-machine (M2M) data processes over the internet. Educators should remember this when developing courses and programs related to the Internet of Everything. Figure 1 shows an image of competency within a professional or IoE context.

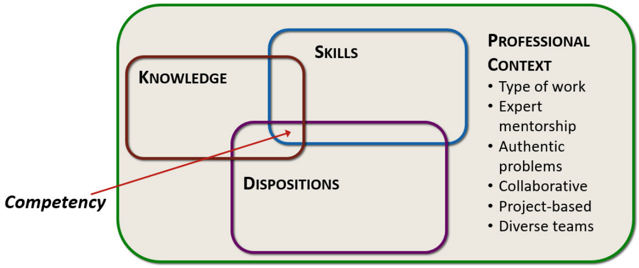

Fig. 1. Visualization of competency from the IT2017 report

From an educational viewpoint, educators have specialized in the knowledge domain of computing and engineering for many decades. However, teachers have also considered student skills over centuries and millennia. For example, becoming an artist or a craftsperson required the tutelage of established artisans who transferred skills to their students. However, they likely needed to pay more attention to their trade’s dispositional and knowledge dimensions. This is unfortunate because, then and now, employers have had a keen interest in hiring people with proper behaviors and some knowledge in addition to the skills students might have. Dispositions reflect the workplace behaviors of a competent individual; knowledge is what an individual knows. Therefore, prospective employers would likely hire a graduate who had demonstrated all or most of the eleven dispositions in addition to skills and knowledge. Promoting dispositions in computing education is, however, still subject to research [5,7,11,13,15,22]. The same applies to teaching and assessing dispositions.

It would be beneficial to highlight a few developments to motivate the reason for fostering competency as a broad need for computing and engineering in IoE settings. Some of the earliest work on computing competencies emerged in software engineering. In 2011, Mead and Shoemaker [16] described the software assurance (SwA) competency model comprising knowledge, skills, and effectiveness. As before, the knowledge dimension is what an individual knows, skills are what an individual can do by applying knowledge, and effectiveness is the ability to utilize knowledge and skills productively. In simpler terms, effectiveness reflects behavior attributes, i.e., dispositions, such as being adaptable, meticulous, or purpose-driven.

The first computing curricular report to include dispositions explicitly was Information Technology 2017 (IT2017), defining competency as the combination of knowledge, skills, and dispositions in context [21]. Dispositions, described as "socio-emotional skills, behaviors, and attitudes that characterize the inclination to carry out tasks and the sensitivity to know when and how to engage in those tasks" [18], were not explicitly listed in IT2017 as they were assumed to be exhaustive and self-evident in human behavior. Subsequent curricular reports such as Information Systems 2020 (IS2020) [14] and Data Science 2021 (DS2021) [2] also embraced competency as a basis for computing education.

3 Curricular Structure and Fundamentals

For an Internet of Everything curriculum structure, first assume a traditional baccalaureate four-year student experience where each year partitions into two semesters. This assumption is common. However, a baccalaureate degree program can vary from three to six years in some locales worldwide.

3.1 Credit Structure

Typically, the four-year arrangement contains 120 semester hours or credits in the U.S. In Europe, a baccalaureate program typically has 180 or 210 points within the European Credit Transfer System (ECTS), earned within six or seven semesters. This translates to 30 credits or 60 ECTS for each full year of an academic program.

Again, the concept of a semester hour or credit can vary worldwide. In the United States, one semester hour or one credit equals 750 min of classroom study. Within the four years of study, the equivalent of one year is often dedicated to general studies and education, such as philosophy and history. The match of another year usually encompasses mathematics, science, and related subjects. What remains are two years of study or the equivalent of 60 credits (semester hours). In China, a university's requirements for a bachelor's degree are typically 120 credits, similar to the requirements in the United States. These credits often include general education credits and the specific technical, mathematics, and science requirements for a degree.

In Europe, one ECTS credit point equals 30 h of student work, including in-class time, self-study or group work, and projects. On average, a European university would award 5 ECTS credits per course. However, it is also possible to award 2, 3, 6, or 8 ECTS for a course. Typically, a university would have six courses per semester, two semesters yearly. Hence, a student typically should achieve 30 ECTS per semester, which equals 900 h of work, the equivalent of a full-time job.

3.2 Mathematics, Science, and General Education

Before delving into IoE subjects in a degree program, it is worthwhile to address some non-IoE areas. Firstly, one year of general studies often reflects the vision and mission of the university or institution. In that sense, such studies are beyond the scope of this work. This curriculum component might also include current elements of diversity, equity, inclusion, and accessibility [8]. Secondly, the year (equivalent to 30 credits or 60 ECTS) of mathematics and science is essential for IoE students since they must be competent in their work and make decisions supported by scientific methods and quantitative and qualitative analysis. Hence, approximately 50% of the curriculum should encompass non-IoE studies, leaving about 60 credits, or 90 to 105 ECTS, for IoE studies. In this paper, we provide credit point suggestions for the U.S. system with suggested ECTS units.

The mathematics and natural science component should encompass the subject areas in support of IoE learning and workplace performance. The 30 credits (semester hours) should include the following areas with credits described in parentheses.

- Discrete Mathematics (3 credits or 6 ECTS)
- Applied Probability and Statistics (6 credits or 12 ECTS)
- Calculus for Business (3 credits or 6 ECTS)
- Quantitative Analysis (3 credits or 6 ECTS)
- Qualitative Analysis (3 credits or 6 ECTS)
- Science with Laboratory (Biology, Chemistry, Physics) (6 credits or 12 ECTS)
- Mathematics/Science Electives (6 credits or 12 ECTS)

The course titles and assigned credits will vary depending on an institution's mission. For example, science courses may have four or more credits each because of content depth and laboratory time.

IoE students need an understanding of discrete mathematics because they require a knowledge of computing machines that operate in discrete rather than continuous modes. Probability and statistics are essential for IoE students because many computing decisions rely on numerical data to form good executions. Calculus is necessary for problem-solving strategies related to applications. IoE students focus on people-to-people and people-to-machine approaches in enterprise environments. Hence, knowing mathematics for business applications is essential for a competent IoE graduate. Analyzing strategic problems may involve quantitative and qualitative methods to extract information from (big) datasets. The techniques needed for exploring such issues will require different strategies. Hence, students should be aware of the two paradigms to address these modes of analysis.

Natural science should be part of an IoE education. The reason is the scientific method used in related subject areas. Because machines/things are part of an IoE paradigm, the scientific learning method is a meaningful way to approach IoE problems. As a suggestion, some form of classical physics would be an adequate choice to address the machine-to-machine or people-to-machine problem-solving strategies. Chemistry or biology could also work but less effectively than physics. Even so, approximately one year of the IoE curriculum constitutes the mathematics and science component.

The fundamental subject areas in mathematics and science should support competency foundations to enhance workplace performance, as already stated. It would also be interesting to attain more information and research to consolidate the integration of mathematics and natural science in IoE learning. However, it is too early to determine why the recommended courses would not satisfy a curriculum to produce a competent graduate.

4 Internet of Everything Curriculum Background

It is not the intention to specify precise IoE subject areas for an IoE curriculum. Instead, the intent is to propose general curricular areas to foster discussion and increased study for a meaningful curriculum. The broad curricular areas must involve the internet with processes and data that include P2P, P2M, and M2M. For simplicity, one can assume commutativity for people-to-machine. That is, people-to-machines and machines-to-people (P2M and M2P) are equivalent to this discussion.

Furthermore, the machine-to-machine aspect of IoE correlates with the Internet of Things (IoT) phenomenon that has emerged over the past quarter century. This term first appeared in 1999 and referred to any machine or thing with a binary (off-on) switch connected to the internet [6]. IoT programs have emerged worldwide, especially in China, where the subject leads to undergraduate and graduate degrees [23]. For perspective purposes, Appendix A shows a four-year IoT curriculum at the Florida International University (FIU). The curriculum at this institution forms an IoT exemplar in shaping a model curriculum for the Internet of Everything.

As mentioned, the general education degree component and the mathematics/science degree component are approximately thirty credits each. Therefore, for a four-year degree involving 120 credits, the IoE component should be about 60 credits. One could partition these credits into required foundation (core) courses, required advanced technical studies, elective technical courses, and free electives. For convenience, one can assume that all courses are three credits each. Therefore, the plan is to develop up to twenty IoE courses for the program. Again for convenience, assume approximately six foundation courses (18 credits), eight required advanced technical courses (24 credits), four elective technical courses (12 credits), and two free elective courses (6 credits). Two of the required advanced technical courses should be significant team projects related to IoE to address the disposition component of competency.

5 Internet of Everything Subject Categories

A breakdown of this plan follows. The course codes are arbitrary and used only for identification. The course names intend to provide meaning in the IoE domain and accentuate the “knowledge” dimension of competency. The “skills” and “dispositions” dimensions are suggestions to fulfill the extent of competency in producing a competent graduate by graduation. The two-course project should exploit all skills and all dispositions of the student. Also, parallel computing is relevant everywhere now, so exposure to parallel computing should be part of all IoE curricula.

5.1 Foundation Category

The Foundation Category comprises approximately six courses or 18 credits. This category should provide the basis for most other IoE activities. The student experiences or courses in this category generally occur within the first two years of study. For example, these courses might be the following.

IOE101 Introduction to the Internet of Everything
IOE102 Computers and Society
IOE103 Introduction to Python Programming
IOE104 Introduction to Web Programming
IOE201 Computer Organization
IOE202 Network Fundamentals and Security

The structure of the Foundation Category suggests new thinking and is adaptable based on the institution's mission. Each course should focus on student performance, where students practice related skills in their learning. The specific skills conveyed to students depend on the institution.

At this level, students become aware of the dispositions or attributes expected in the workplace. For example, teachers could promote collaboration with programming pairs or teams or require the meticulous application of network fundamentals. The early development of dispositions and skills, in addition to knowing content, is a positive first step in producing a competent graduate in the discipline.

5.2 Advance Category

The Advance Category comprises eight courses or 24 credits. This category of courses must build on the experiences developed in the Foundation Category. These student experiences generally occur in a four-year program's second and third years of study. The suggested courses are as follows.

IOE203 Elements of Data Structures
IOE204 Introduction to Data Science
IOE301 User Experience
IOE302 Data and Data Analytics
IOE303 Parallel and Distributed Processing
IOE304 Database Systems
IOE305 Social Informatics Operating Systems
IOE306 Internet of Everything Networking

As with the foundation courses, this category should suggest new thinking and is adaptable based on the institution's mission. Again, the focus should be on student performance, where students continue to develop skill sets coupled with the continued awareness of the dispositions expected in the workplace. Educators should foster as many of the dispositions shown in Table 1. The goal is to develop competent IoE graduates with the right attitude (dispositions) and the necessary skills to perform successfully in the workplace. In addition, teachers should enhance the people-to-people, the people-to-machine, and the machine-to-machine paradigms when offering courses in the Advance Category.

5.3 Electives Category

The Elective Category consists of four courses or 12 credits selected from a list of experiences related to the IoE. The following suggested courses often occur in the last year of study. However, students may also choose them with the intent of some IoE specialization. The following list is a suggestion. Institutions should offer electives based on their needs and mission.

IOE401 Computing Ethics
IOE402 Machine Learning
IOE403 Internet of Everything Project Management
IOE404 Internet of Everything Application Security
IOE405 Cloud Computing
IOE406 Embedded Systems for IoE
IOE407 Principles of Cybersecurity
IOE408 IoE Sensors and Controllers
IOE409 Software Strategies for IoE
IOE410 Wireless Protocols
IOE411 Internet of Everything Entrepreneurship
IOE412 System Design and Implementation
IOE413 Operating Systems
IOE414 Advanced Topics on the Internet of Everything
IOE415 Internet of Everything Systems
IOE416 Strategies for High-Performance Computing

As with the Advance Category, educators should enhance the P2P, P2M, and M2M paradigms in elective courses. Again, promoting and assessing dispositions and skills is essential for these student experiences [8,12].

5.4 Project Category

The Project Category comprises two courses or 6 credits. This category should be the most important of all the categories. Students should focus on a challenging project and dig deep into learning and skill development. All eleven dispositions should be active, and a complement of skills should emerge in developing competency and demonstrating performance.

IOE491 Major Project 1
IOE492 Major Project 2

All projects should be highly structured with an IoE focus (e.g., P2P, M2P, or M2M). This finishing computing experience should focus on the knowledge, skills, and dispositions acquired in earlier coursework. The project should incorporate proper computing standards (e.g., IEEE and ISO standards) and multiple realistic constraints (e.g., security, welfare, social, and economic factors). In addition to educators, people from business and industry should assist in evaluating all significant projects.

5.5 Free Category

The Free Category consists of two courses or six credits. This category suggests that students should be able to learn additional topics on the Internet of Everything or explore new areas of learning such as music, art, or business. In addition, all students should be free to discover areas of their interest, contributing to holistic personal development upon graduation [19,20].

6 Conclusions and Future Work

This effort is a work in progress as a first step in establishing a curriculum for the Internet of Everything. This competency-based approach (knowledge, skills, and dispositions) ensures that IoE graduates are ready for the workplace. The IoE curricular structure followed a four-year pattern. However, other ways are also possible based on geographic region and custom. In all cases, an equivalent of at least two years or 60 credits encompasses the technical portion of an IoE curriculum.

Establishing a new curriculum is complex and will face several challenges, e.g., resistance to change, lack of resources, and the need to prepare educators respectively. Most people have yet to discover the Internet of Everything and IoE education and will need time to develop. One of the first challenges is understanding what IoE is. This same challenge affected the Internet of Things in its early days, but now most people understand IoT and curricula exist for this branch of computing. Another challenge is the establishment of an IoE community of educators. That community would begin to emerge as IoE and IoE education proliferates in college and university courses and eventually in IoE curricula and degree programs. Time will tell how IoE will progress. First, however, presenting some basic ideas about IoE and IoE education is essential.

This work still needs time for completion. The intention is that this first step will encourage researchers to generate new perspectives and discussions on an IoE curriculum. Furthermore, since IoE is a superset of IoT, an IoT curriculum should only be part of an IoE curriculum. In addition to a things-to-things (T2T) paradigm, IoE must address the people-to-things P2T) and the people-to-people (P2P) paradigms. Hence, the Internet of Everything could open new doors and ideas encompassing various computing competencies. Thus, IoE represents a new dimension in computing education.

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Appendix A

FLORIDA INTERNATIONAL UNIVERSITY (FIU)

INTERNET OF THINGS TECHNICAL CURRICULUM

https://internetofthings.fiu.edu/courses/

Core Courses
CGS 2518 Data Analysis (3)
CGS 3767 Computer Operating Systems (3)
CDA 3104 Introduction to Computer Design (3)
CEN 3721 Introduction to Human-Computer Interaction (3)
COP 2250 Programming in Java (3)
CTS 1120 Fundamentals of Cybersecurity (3)
CNT 3122 Sensors for IoT (3)
CNT 3142 Microcontrollers for IoT (3)
CNT 3162 Intro. to Wireless Communications for IoT (3)
CNT 4165 Network Protocols for IoT (3)
EGN 2271 Introduction to Circuits and Electronics (3)
EEL 2880 Applied Software Techniques in Engineering (3)
EEL 4730 Programming Embedded Systems (3)
EEL 4734 Embedded Operating Systems (3)
EEE 4717 Introduction to Security of IoT and Cyber-Physical Systems (3)
TCN 2720 Intro to IOT (2)
TCN 4211 Telecommunications Networks (3)
TCN 4940 Senior Project (3)

Electives

Network Forensics & Securitys
TCN 4081 Telecommunication Network Security (3) (Prereq: TCN 4211)
TCN 4212 Telecommunication Network Analysis and Design (Prereq: TCN 4211)
TCN 4431 Principles Network Mngmt & Control Standards (Prereq: TCN 4211)
IoT Privacy (New Course, Prereq: EEL 2880)
Wireless Protocols for IoT (New Course, Prereq: TCN 4211)
IoT Forensics (New Course, Prereq: Embedded Programming for IoT)

Cyber Security
EEL 4806 Ethical Hacking & Countermeasures (Prereq: EEL 2880)
EEL 4802 Intro. Digital Forensics Eng. (Prereq: EEL 4806)
EEL 4804 Intro. Malware Reverse Eng. (Prereq: EEL 4806)

Data System Software
MAD 2104 Discrete Mathematics
COP 2210 Programming I

COP 3337 Programming II (Prereq: COP 2250 or COP 2210 or EEL 2880)
COP 3530 Data Structures (Prereq: COP 3337 and MAD 2104)
COP 4338 Computer Programming III (Prereq: COP 3350)
COP 4604 Unix Programming (Prereq: COP 4338, Coreq: COP 4610)
COP 4610 Operating Systems Principles (Prereq: COP 4338)

Entrepreneurship
EEL 4933 Engineering Entrepreneurship
EEL 4062 Engineering Business Plan Development
EEL 4351 Intro to Business Decisions.

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