Teaching the Internet of Things (IoT)

Gary J. Mullett
Springfield Technical Community College

I. Overview

For those of us who have been teaching electronics centric technologies for a long time, the advent of integrated circuits (ICs) during the early 1960s and the subsequent embrace of digital electronics during the next few decades was a watershed moment for it began to provide a guide or roadmap to where this technology was headed. Until that time, the world of electronics was analog in nature and active electronic devices were just that – discrete, single function devices (i.e. vacuum tubes or transistors) that needed to be combined with other discrete devices to produce a useful electronics based product like a radio or television. Certainly, advances in technology occurred before the IC existed but only at a limited pace and without providing a very clear picture of the future. During the 1970s and 1980s, new computer memory chips were released in a predictable fashion and one could point to what the size of the next IC would be and how soon it would become available. One might say that the IC and its long continuous progression of micro-miniaturization (as predicted by Moore's Law), has changed what we conceive of that is possible with electronics-based systems. Today, more than five decades after Moore's prophetic prediction, electronics is ubiquitous in our everyday lives and has changed how we live, work, learn, play, communicate, and socialize.

During the last decade of the past millennium, several electronics-based technology areas (personal computers [PCs], digital communications, and computer networking) had evolved enough to facilitate a convergence of these technologies to enable the realization of another emerging technology paradigm now known as the Internet. Now today, at this point in time roughly twenty-five years later, the life changing effect of the Internet on society and how humans interact is taken for granted. Currently, with the advanced sophistication of inexpensive embedded controllers, wireless networking technologies, and innovative sensor networks, another emerging technology has become the newest techie buzzword or phrase. Commonly known as the Internet of Things (IoT), this technology has the real potential to affect nearly every aspect of human endeavor and commerce by increasing system efficiency and reducing energy consumption. Furthermore, if applied correctly, IoT applications can provide real-time monitoring of the nation's infrastructure and environment and have the potential to improve public health, safety, and national security. A fairly common definition of the IoT is that it consists of "things" (physical entities) that are networked together. These physical things typically consist of sensors and actuators, have processing capabilities (embedded controllers), and software that allows them to perform functions and to communicate with other things. Taken together, these IoT networks allow for the creation of applications that can be used to improve present systems or even create cyber-physical systems to electronically control devices or systems that here-to-fore could not be implemented in real-time. This last statement can be interpreted to encompass control systems like those that enable autonomous vehicles or geographically large systems like "smart grid" architectures for delivering electrical energy more efficiently. Another consequence of the adoption of IoT technology is that the nature of the traffic on the Internet shifts from predominantly human initiated traffic (clicks on a web page and then server downloads) to largely machine-to-machine or M2M communications. This last fact is the driving force behind the newest 5G cellular standard and the proposed future 6G standards that are being driven by envisioned IoT apps [1], [2], [3]. Most observers of IoT technology believe that this is part of the natural evolution of the Internet (i.e. Internet 2.0) and predict that the majority of new devices connected to the Internet will be IoT related and that their number will grow exponentially. The following graphic from IOT Analytics indicates this trend over the past decade and a reasonable prediction for the future. As this technology matures and becomes more commonplace there would presumably be a need for a workforce with the skill-sets needed to deal with it where it is installed. For lack of a better term, people with these skill-sets might be known as IoT field technicians. This paper will detail how one particular community college is addressing the need for training in this area.

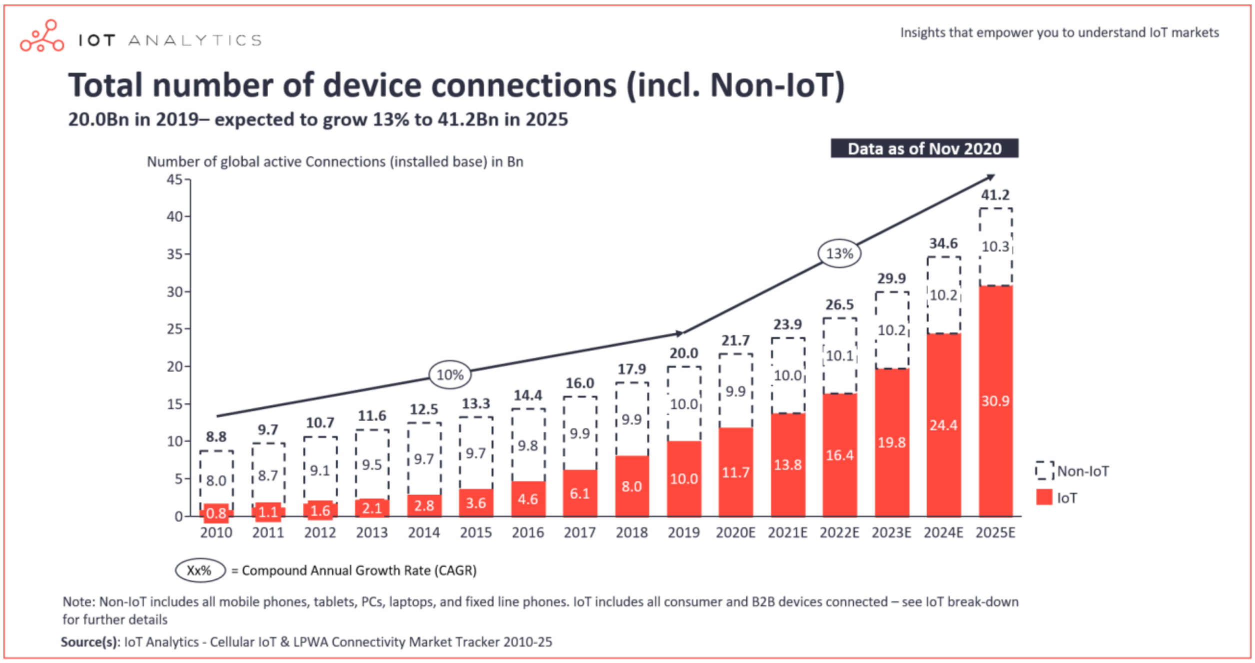

Fig. 1. Total number of connected Internet devices.

II. Synergistic Activities

During the 1990s, Springfield Technical Community College (STCC) of Springfield, MA offered several popular Associate Degree programs in electronics centric areas. Known as the Electronics Group the degrees where in Electronic Systems Engineering Technology (ESET), Computer Systems Engineering Technology (CSET), and Laser Electro-Optics Technology (LEOT). As the Department Chair at the time, with twelve full time and several part-time faculty, this author liked to tell people that we had a “critical mass” of expertise that covered the most important electronics-based technologies of the time. We also taught all the enabling technologies that were driving the emerging Internet. It seemed reasonable that as we surveyed what was happening in the field that we needed to add both telecommunications and networking components to our offerings. This author applied for and was awarded an NSF ATE grant (1996) to develop a telecommunications and networking associate degree (indeed, this new degree was added to AS degree program offerings as Telecommunications Technology in 1997). At the same time, the NYNEX corporation was looking to develop a program to train their present employees (linesmen) in the field of telecommunications since the company envisioned that its future lay in the delivery of entertainment media over copper wre pairs via the Internet and the company needed to transition their employees to this new transmission technology. Also, during the same time period, a meeting with the NSF paved the way for the college to apply for and be awarded a fairly large grant to develop an NSF ATE Center for telecommunications technology building on the earlier NSF ATE project grant. These events have been documented elsewhere [4], [5], [6] and will not be repeated in any great detail here. Suffice to say that faculty from the Electronics Group developed the NSF proposal for the NSF ATE Center which was originally known as the Northeast Center for Telecommunications Technology (NCTT) and was renamed the National Center for Telecommunications Technology (same acronym) and finally became the Information Communications Technology (ICT) Center. These same faculty ran the Center as Co-Directors. All of these developments were not lost on NYNEX and they named STCC as the New England lead college for their multi-million-dollar NextStep employee training program with several of the faculty co-directors from the NCTT center as leaders/coordinators for the curriculum development of the newly created NextStep program. The NextStep program ran for close to twenty years before being phased out in the mid-2010s. This author's involvement with the NCTT center continued until 2004 when he felt that the basic mission of the center had been realized, the new Telecommunications Technology AS degree had been successfully established, as well as, an industry specific Telecommunications Technology AA degree for NYNEX (eventually, named Bell Atlantic and then/now Verizon), and his interest in applications enabled by the Internet overrode the new directions that the Center was moving towards. During the early 2000s, this author received a CCLI grant to develop a wireless telecommunications lab which was instrumental in providing the ability to add new wireless courses to the electronics and telecommunications curricula. Technology marches on and this author recognized emerging trends in the uses of networks and in particular sensor networks. In 2007, this author received a $200K NSF CCLI grant titled "*The Sensor Network Education Project*" [7]. This project was followed in 2010 with another fairly large ($508k) NSF ATE grant titled "*The Intelligent Infrastructure Education Project*" [8], [9], [10], [11]. One of the products resulting from this grant was the development of a new technology course named "The Internet of Things". This author presently has a $600k NSF ATE grant titled "*The Internet of Things (IoT) Education Project*" [12], [13], [14] that has as a goal the development of a one-year IoT certificate of completion as an option to the CSET program. As one might observe, these NSF grants have built upon one another with the current ultimate goal of creating a technology program that provides the skill-sets needed by workers that deal with the technology of the IoT field.

III. The Internet of Things Certificate

Presently, Springfield Technical Community College offers a one-year Certificate-of-Completion titled **Internet of Things** (IOT.COC) [14] under the CSET program. This certificate is the product of several NSF ATE grants that allowed faculty to research the enabling IoT technologies and the development of curricula germane to the subject area. The courses that make up the IOT.COC curricula are a combination of courses from the CSET program and new courses that have not been offered before. The centerpieces of the certificate are the following courses: ELE-111 Internet of Things, ELE-128 Internet of Things Networking and Security, and ELE-168 Developing the Things for the Internet of Things and their associated labs. This paper will highlight ELE-111 - Internet of Things, a three-credit course with an accompanying 1 credit lab and to a lesser extent will talk about ELE-128 - IoT Networking and Security with its accompanying lab. As of yet, ELE-168 and its lab have not been offered. Shown below is a list of required courses for the certificate (certificate requires 24-25 credits total) [15]. The reference given provides a link to the certificate and further links to course descriptions and Student Outcomes.

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 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 from the following list:

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)

Students who complete the CSET program can take additional courses to complete the certificate or students from other disciplines can take what they need to complete the certificate. The certificate was designed to allow students that are in non-electronics-based technologies to get the necessary basics about electronics, embedded control, wireless, and networking to be able to deal with IoT applications implemented for use in their discipline.

IV. The Internet of Things Course

The Internet of Things course (ELE-111) and the associated lab (ELE-111L) are the result of several years of experimentation with different goals for student outcomes and various course objectives driving the process. Furthermore, the availability of Arduino platforms and today, platforms that emulate the Arduino have changed the hands-on aspect of the lab course. The follow table shows the weekly topics covered in ELE-111 during the semester.

Table 1. Weekly topics.

Week	Topic
1	Introduction to the Concepts of IoT
2	Cisco Netacad Course & Cyber-Physical Systems
3	Cyber-Physical Systems, Microcontrollers, & TinkerCad
4	IoT Control Systems & Concepts of Electrical Theory
5	Electrical Units & Ohm's Law
6	Circuits & Frequency Sensitive Components
7	Active Devices
8	Signals & Systems
9	Fog, Cloud, and Mist Computing
10	Sensors
11	Sensor Networks
12	Wireless Technology Standards
13	Introduction to Wireless Networking Technology
14	Intro to Wireless Networking Technology & IoT Case Studies
15	IoT Case Study – Autonomous Vehicles

What the table does not show is the fact that the students are also enrolled in the on-line Cisco Netacad Internet of Things course (IoT Fundamentals: Connected Things). This overview type consists of six chapters and chapter assessment. They have twelve weeks to complete this on-line material which is presented with an IT slant by Cisco. The course material shown in Table 1 is presented with an operational technology (OT) slant since the vast majority of IoT applications address OT functions. The six chapters for the Cisco online course are: (1) Things and Connections, (2) Sensors, Actuators, and Microcontrollers, (3) Software is Everywhere, (4) Networks, Fog and Cloud Computing, (5) Digitization of the Business, and (6) Create an IoT Solution.

The hands-on lab starts with several electrical circuits labs that give the students practice with measuring electrical quantities (ohms, volts, and milliamps), practice building several simple circuits, and practice using an Arduino platform to provide power to light LEDs. Then the students perform the labs specified for the SparkFun Inventors Kit 4.0. These labs give the students experience with programming the Arduino with the Arduino IDE (Integrated Development Environment), interfacing simple sensors and controls to provide digital inputs for variables in running programs, and interfacing various actuators to be powered by output signals from programs running on the Arduino platform. Finally, the students build a complete capstone project that acts as a collision avoiding robot.

The other new course in the IoT certificate curriculum that has been taught is ELE-128 – IoT Networking and Security and its lab, ELE-128L [16,17]. The references given here are links to that course and its associated lab. This three-credit course expands on the material covered in ELE-111, Internet of Things, and concentrates on building and managing secure networks of IoT devices. The primary focus of this course is demonstrating how to securely network IoT devices into a system. Network topics include local and wide-area network principles, wired and wireless networking for IoT, and specialized communication such as Bluetooth, Zigbee, LoRa, and cellular networking. Topics will include the assessment of device security, attack surfaces, mitigating the threats created by insecure IoT devices, evaluating the security of the complete system, IoT security best practices, and techniques to securely integrate collections of "things". The course demonstrates how data is exchanged between the IoT devices in the field and websites or cloud servers such as Google Cloud, Amazon Web Services (AWS), or Microsoft Azure. The backend server forms the data collection center of the IoT network. Common protocols such as MQTT, REST, and CoAP as well as "Big Data" concepts are discussed. Information security and privacy are key concerns of the course. The lab portion of the course gives the students hands-on experience with the topics covered in the course.

The ELE-111 course and ELE-111L lab have been extremely popular with full enrollment each semester for the last two years since the adoption of the present syllabus. Of course, during the 2020-2021 academic year the course was offered online both semesters with the lab in-person with restricted enrollment numbers due to COVID-19. So, presently, the course is available in both modalities (however, on-line only Fall 2021). The lab has been adapted for online delivery but is only being offered in person for the Fall of 2021.

V. The Future

As IoT applications are adopted on a larger scale it is assumed that the IoT certificate will become more popular with additional interest from individuals in fields that are adopting this type of technology but do not teach any of the basics about it. One may have noticed that two possible courses listed in the certificate curriculum include a course on Programmable Logic Controllers (PLCs) and its associated lab and a course on Biomedical Wireless Networks and its associated lab. These courses give IoT certificate students the ability to pick up some basic skills about these topic areas without taking the entire two-year programs that those courses are associated with. This is an exciting and rapidly growing area with the additional promise of built-in machine learning (ML) driving the artificial intelligence (AI) aspects of these IoT enabled control systems. The inter-disciplinary nature of the IoT area will most likely drive other solutions to provide the skill-sets needed by the technicians that will work in this area. Our certificate program is but one attempt to provide education/training to help tackle this developing need.

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