Creation of an Internet of Things (IoT)-Based Innovation Lab

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Introduction

Internet of Things (IoT) technology has transformed almost every industry sector, including but not limited to energy, healthcare, transportation, manufacturing, retail, and agriculture. This evolution has opened up an era of innovation and economic growth that is surpassed by none, in recent times. Business reports from Cisco estimate that there will be 50 billion devices connected to the Internet by 2020[1], and that $19 trillion in IoT value is at stake over the next decade[2]. Likewise, the federal government spent $8.8 billion in the fiscal year of 2015 on infrastructure, software, and cyber security solutions for IoT[3]. This creates a rising demand for IoT-trained graduates in the workforce, and as educators, we are tasked with bridging this skills-gap.

This paper is the first of a sequence that will document the creation of an Innovation Laboratory at Seattle University, as part of a three-year project. This initiative aims to provide a platform for a curriculum rich in IoT-related skills, and serve as a space that fosters innovation and creativity. The curriculum enhancement aspect of this project focuses on incorporating IoT-based hardware and software platforms in both core and elective undergraduate Electrical and Computer Engineering (ECE) courses. The research aspect aims to stimulate students' intellectual curiosity by engaging them in scientific inquiry and student-driven projects that cultivate an informal learning environment that promotes critical thinking, and interpersonal and technical skills[4]. Our underlying aim is to achieve a pedagogical transformation that empowers a new generation of engineers equipped with skills essential and relevant to the technical workforce. This project was funded by a generous grant from W. M. Keck Foundation.

This paper highlights the motivation behind this initiative, discusses the proposed plan of action, and presents initial results and observations from a pilot implementation of this initiative, specifically focusing on the curricular enhancement aspect of the project. Efficacy of this implementation was gauged using feedback from student-surveys. Progress towards the goals of this project will be documented in subsequent papers.

An Overview of IoT

Internet of Things (IoT) is a technology that uses physical objects or "things" embedded with communication capabilities, enabling intelligent data exchange among such devices or between these devices and other internet-enabled systems. Within the last decade, we have witnessed a proliferation of commercial IoT products, some of which include smart lighting and thermostats, health monitors and activity trackers, and connected devices for smart home and smart city applications. In a nutshell, IoT bridges the divide between the physical and digital worlds. This may well be the single most important technology movement of this decade, and not surprisingly, skills related to IoT and its enabling technologies are highly sought after in the engineering workforce.

The term 'Internet of Things (IoT) was first used by British technologist, innovator, and consumer sensor expert, Kevin Ashton, during a presentation at Procter & Gamble the spring of 1999; the context was Radio Frequency Identification (RFID) for supply chain management. In his blog, 'Beginning the Internet of Things', Kevin states that 'The only thing I can perhaps claim sole credit for is the name: three ungrammatical words that now label computing's future'[4]. While the term 'IoT' is relatively new, the concept of connected systems for remote monitoring has been around for decades. The recent popularity of IoT can be attributed to an important factor; advances in its enabling technologies. This includes miniaturization of devices, low-cost and high-speed networking and communication, and the rise of cloud computing and data analytics[5]. In the realm of ECE education, IoT is an ideal platform that encompasses hardware and software design, along with a systems integration approach. The traditional undergraduate ECE curriculum may include core or elective courses that introduce students to various enabling technologies of IoT, such as data acquisition, computer networks, wireless communication, embedded system design, and digital signal processing, among many others. This provides an opportunity to leverage existing courses in order to incorporate aspects of connectivity and remote monitoring in undergraduate education.

In the past few years, quite a few universities have been establishing centers for IoT research, mostly in collaboration with local industry. The University of Wisconsin, Madison IoT lab serves as a campus hub for university-industry collaborations, with a focus on learning, research and hands-on skills[6]. The University of Massachusetts, Dartmouth IoT Research lab is a multidisciplinary initiative to explore diverse applications of IoT[7]. In 2015, Carnegie Mellon University, in collaboration with Google, launched an expedition to turn its campus into a living laboratory to create a robust platform that will enable Internet-connected sensors, gadgets and buildings to communicate with each other[8]. While these research groups are actively involved in cutting-edge IoT research, their primary focus is not on undergraduate education. With the exception of IoT summer Research Experiences for Undergraduates (REU) programs offered by the University of California, Irvine and Texas State University, among others, IoT research is largely concentrated in graduate programs. To the best of our knowledge, our initiative to achieve a holistic integration of IoT throughout the undergraduate ECE curriculum is one of its kind.

Plan of Implementation

Our approach to incorporating IoT in the ECE curriculum is not limited to a stand-alone course on IoT; rather, it is a holistic integration of IoT skills and related technologies throughout the undergraduate program. Through this initiative, undergraduate students will be exposed to applications of IoT in the context of core and elective ECE courses, thus enabling them to be better prepared for careers in a world that is more "connected" now, than ever before. This initiative will also support undergraduate research in IoT, thus affording students an opportunity to gain a deeper understanding of the subject, in a real-world context. The proposed curriculum framework would support learning outcomes that transcend a basic understanding of concepts, and aim towards the application of acquired skills in designing, building and deploying IoT devices for a variety of applications. Unlike most other ECE programs, our department offers students, beginning in their freshman year, a curriculum that is rich in experiential learning, supported by a core curriculum that embodies the spirit of service, social justice, leadership, and ethical reasoning. In addition to curricular enrichment, the Innovation Lab would serve as a 'makerspace' for our student community. Providing access to modern equipment and tools would give students the opportunity to tap into their creativity, and to use skills acquired both in-and-out of classroom, thus enabling the transformation of raw ideas to working prototypes of devices.

The ABET accredited curriculum in the Department of Electrical and Computer Engineering at Seattle University is unique because it incorporates a significant number of ECE courses during the freshman and sophomore years. The advantage of this design is that students get a flavor of ECE right at the onset of their undergraduate program, unlike most other ECE programs wherein students are exposed to technical courses only in their junior year and beyond. We aim to use this as a leverage to enhance our existing curriculum by incorporating IoT-based activities in relevant core and elective courses. This includes two new stand-alone courses on IoT, one of which is currently being offered in winter 2017. The targeted core courses include Digital Operations and Computation, and Computing for Engineers in the freshman year, and Programmable Devices, Microprocessor Design, and Computer Tools in the sophomore year. Junior and senior level elective courses such as Embedded Systems, Wireless Communication, Data Communication, Digital Image Processing, and Renewable Energy Systems. Our current curriculum includes, in the junior year, a series of laboratory experiences with emphases in Circuits (Fall Quarter), Electronics (Winter Quarter), and Signals and Systems (Spring Quarter). This lab sequence is designed to equip students with skills necessary to successfully complete a year-long junior design project that has a unique theme each year; we aim to design an IoT-themed project for AY 2018-2019. Through the proposed initiative, we foresee that ECE students will encounter an IoT-enhanced course at least thrice per year, throughout their undergraduate program. Based on prior enrollment data, this translates into an average cohort size of 140 students per year.

This initiative will facilitate both funded and volunteer undergraduate student engagement in IoT research. Seattle University encourages undergraduate scholars to submit abstracts to the National Conference of Undergraduate Education (NCUR). Undergraduate researchers supported by this project will be encouraged to submit abstracts to NCUR, and other technical conferences that are based on advances in IoT and Sensors. We anticipate that the cumulative efforts of our undergraduate researchers will culminate in innovative technologies that benefit humanity, examples of which may include assistive technologies for people with special needs, and quality of life improvement for people in under-developed countries. For some students, it could be a transformative experience wherein they may discover a passion for scholarly research, and pursue a path in academia[9].

In addition to the curricular benefits of the Innovation Lab, this initiative aims to harness the workspace and resources to inspire curiosity, exploration, and discovery, resulting in a deeper understanding of IoT and its applications. When not in use for curricular or research purposes, we aim to make the lab available to our student- hobbyists, technical chapters, and technical special interest student groups, on a time-shared basis. As part of this project, we will coordinate with campus student chapters such as IEEE, IEEE-HKN (Eta Kappa Nu), SHPE (Society of Hispanic Professional Engineers), and SWE (Society of Women Engineers) to develop group projects that are geared towards the application of IoT for humanitarian engineering. A key feature of makerspaces is the intersection of formal and informal learning through designing, collaborating, inquiring, mentoring, experimenting, problem solving, and inventing [6]. This lab will provide the means to cultivate an informal learning environment that promotes critical thinking, and interpersonal and technical skills. Our department is currently home to a few self-initiated special interest research groups, with focused interests such as assistive technologies, environmental monitoring, and robotics. It is our hope that the Innovation Lab will inspire the genesis of many more of these groups.

Observations

As a first step towards implementing this project, a stand-alone course on IoT is being offered as an ECE elective in winter 2017. This course introduces students to various aspects of IoT; hardware and software platforms, networking and communication protocols that drive IoT technology, security vulnerabilities of IoT devices, and applications of IoT in a variety of sectors. This course also includes a lab component that gives students an opportunity to work with a variety of hardware development boards and web application platforms. An important deliverable for this course is the design and prototype construction of an IoT device. Results and observations from this ongoing course will be documented in a subsequent paper.

A pilot implementation of this project was conducted in the fall quarters of 2015[10] and 2016, in an ‘Introduction to Engineering’ course that introduces pre-engineering freshman students to various disciplines in engineering. Each engineering department hosts interactive sessions that include an overview of the discipline, curriculum, sub-disciplines and career pathways, and a hands-on activity session that highlights important aspects of the corresponding discipline. The activity chosen by the Electrical and Computer Engineering department in fall 2016 was based on Bluetooth Low Energy (BLE) communication between a Cypress BLE Pioneer Kit and an Android application. A detailed tutorial walked students through the hardware setup, firmware programming, communication with the Android app, and using simulated data to implement a variety of IoT applications, including a heart-rate monitor, glucose meter, and a ‘Find Me’ device tracker. This activity was designed and executed keeping in mind the fact that freshman students may have limited knowledge and experience with the concepts involved. The underlying goal of the pre-lab lecture and hands-on activity was about to educate pre-engineering majors about the myriad opportunities they could have as ECE graduates, and to help them understand the relevance of core math, science and ECE courses in the context of a bigger picture.

A post-activity survey was administered to the freshman class of ten students, primarily to solicit feedback on their experience with the introduction to IoT lecture, and the hands-on BLE activity. Student responses were typically in the form of selecting a numerical value or rank that indicated their level of agreement on the six statements listed in Table 1, pertaining to their experience with the IoT session.

Survey question #1 asked respondents to indicate their level of agreement on whether the session was successful in demonstrating the confluence of Electrical and Computer Engineering, and the corresponding responses are shown in Figure 1.a. It can be observed that 100 percent of the respondents agreed, ranging from strongly to slightly, that the IoT session highlighted aspects of both disciplines. While the hands-on activity was more inclined towards computer engineering, the introductory lecture session introduced students to the sub-fields of ECE and the versatility of IoT; this experience could have influenced their response in favor of the statement. Survey question #2 asked respondents to indicate their level of agreement on whether the session introduced them to various aspects of building an IoT device, and the corresponding responses are shown in Figure 1.b. Again, 100 percent of the respondents agreed with this statement, with a majority of them in strong agreeance. Designing hands-on activities for freshman students has its own constraints, an important one being the need to shield them from complexities and intricacies of hardware/software design. Perhaps, a combination of lecture and lab could give them confidence in their ability to successfully build an IoT device, without significant prerequisite knowledge.

Survey question #3 asked respondents to indicate their level of agreement on whether the session enhanced their interest in IoT applications, and the corresponding responses are shown in Figure 1.c. It can be observed that 80 percent of the respondents agreed with the statement, while 20 percent slightly disagreed. For students who disagreed, the authors hope that continued exposure to commercial IoT devices in their day-to-day lives would change their opinion. IoT is a powerful and pervasive technology, and it is bound to impact the way we interact with the physical world. Survey question #4 asked respondents to indicate their level of agreement on whether the session changed their perception of ECE, and the corresponding responses are shown in Figure 1.d. It can be observed that 80 percent of the respondents indicated a change in perception, while 20 percent didn't. Of the two respondents who stated that the IoT session didn't change their perception of ECE, one was a student who maintained an interest in ECE after the session.

Responses to survey questions #5 and #6 are shown in Figures 1.e and 1.f, and they reflect the impact of the IoT session on the respondents' enhanced interest of ECE, and their motivation to strongly consider it as a choice of engineering discipline. It can be observed that 80 percent of the respondents indicated an enhanced interest in ECE, and 60 percent stated that they would consider ECE as a potential choice for an engineering discipline. Ideally, it would be expected to see a higher percentage of positive responses in these two categories, however, the authors acknowledge the fact that students' choice of discipline could be influenced by a number of factors, and the main goal of recruitment efforts is to give students the resources needed in order to make an educated decision.

Table 1: Survey questions #1 to #6

	Agree					Disagree
The Internet of Things (IoT) lecture and activity session						
1. Demonstrated the confluence of 'Electrical' and 'Computer' Engineering	1	2	3	4	5	6
2. Introduced the various aspects of building an IoT device	1	2	3	4	5	6
3. Got me interested in IoT applications	1	2	3	4	5	6
4. Changed my perception of ECE	1	2	3	4	5	6
5. Enhanced my interest in ECE	1	2	3	4	5	6
6. Will motivate me to consider ECE as a choice of engineering discipline	1	2	3	4	5	6

For the remainder of this project, we will seek the services of an assessment expert who will work closely with the authors to determine measurable assessment criteria, and develop a framework using performance indicators for monitoring the progress towards the criteria used for project evaluation. A mid-term SWOT analysis will be conducted in summer 2018 to evaluate the strengths, weaknesses, opportunities, and threats to the project. These observations will dictate the best path moving forward, and provide the opportunity to take advantage of the strengths, address weaknesses, capitalize on opportunities, and avert threats. The overall success of this project will be evaluated in the end-of-term performance assessment that will be held in fall 2019. Formative and summative assessment data will be obtained on a quarterly basis, from student and faculty surveys, and focus groups. In addition to providing a measure of success of the project, assessment and evaluation efforts would help us gauge the impact of our initiative on student learning, provide diagnostic feedback regarding the execution of the project, and serve as a platform for continuous improvement of the current project, and related future enhancements.

Future work and conclusion

As part of this project, the authors will continue incorporating relevant IoT activities in a wide range of core and elective courses. Courses chosen for AY 2017-2018 include Introduction to Engineering, Computing for Engineers, Programmable Devices, Embedded Systems, Microprocessor Design, Data Acquisition, Digital Image Processing, and Electrical Energy Systems. In addition, undergraduate research projects that focus on connected devices will be facilitated. Results and observations from these implementations will be documented in a subsequent paper.

Studies show that unlike several technology trends that fail to meet expectations, and eventually succumb to bleak earnings, Internet of Things is here to stay. Forecasts and market

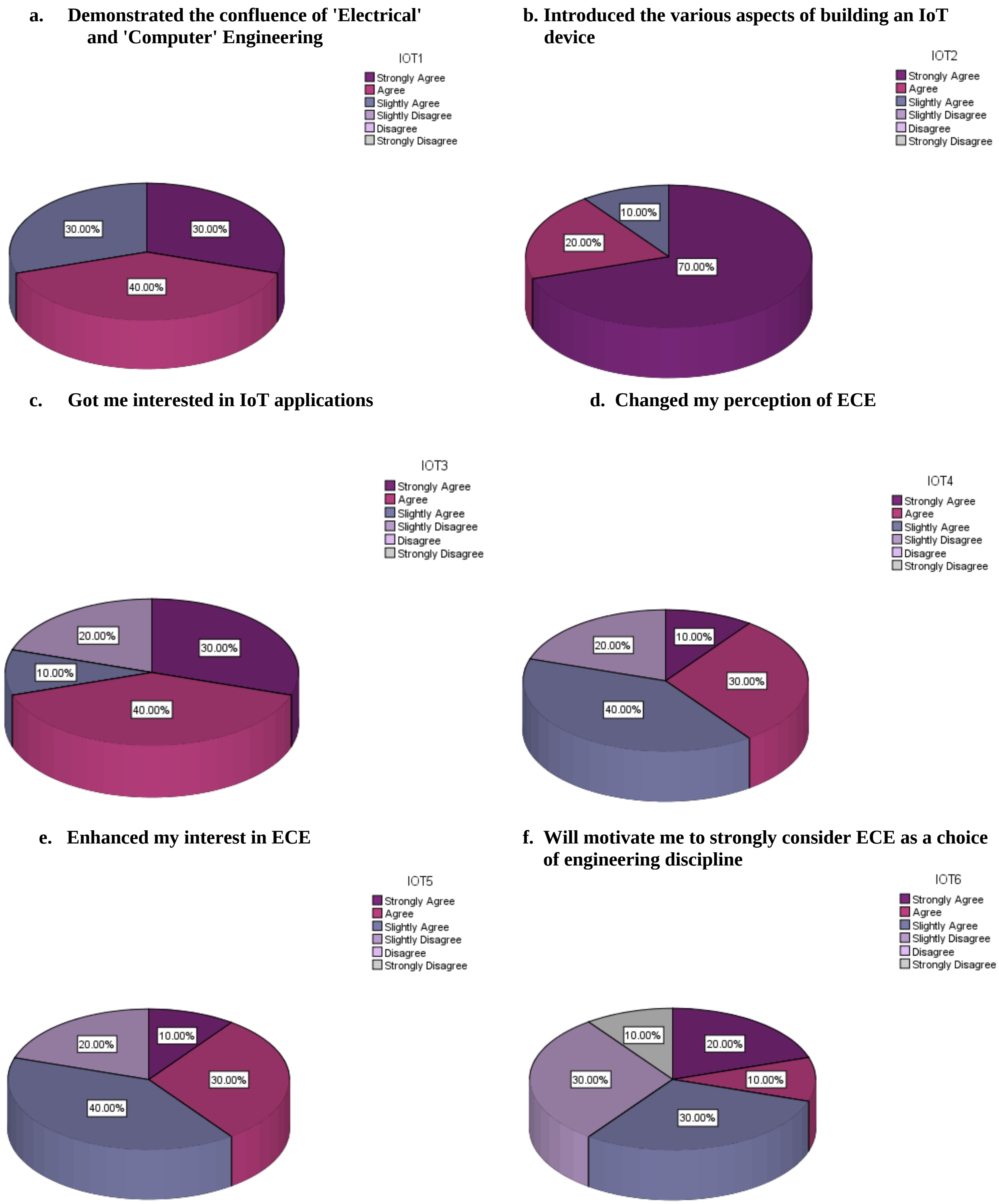

Figure 1: Survey responses indicating students' level of agreement on the impact of the IoT session

estimates point towards a promising Compound Annual Growth Rate (CAGR) of 23% from 2015 to 2021. This upward trend will, undoubtedly, open doors of opportunities for graduates with IoT-related skillsets. The positive reinforcement provided by these statistics drives our continued efforts towards providing IoT education and training to future graduates.

References

1. https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf
2. http://www.cisco.com/c/dam/en_us/services/portfolio/consulting-services/documents/consulting-services-capturing-ioe-value-aag.pdf
3. http://www.businessinsider.com/the-us-government-is-pouring-money-into-the-internet-of-things-2016-5
4. Ashton, K., 2016, "*Beginning the Internet of Things*", Web blog post, medium.com, 18 Mar. 2016.
5. Rose, K., Eldridge, S., Chapin, L., *The Internet of Things: An Overview. Understanding the Issues and Challenges of a More Connected World*, Internet Society, Geneva, Switzerland, October 2015.
6. http://www.iotcenter.wisc.edu/
7. http://www.umassd.edu/engineering/ece/research/keyresearchareas/computerengineering/iotresearch/
8. https://www.cmu.edu/integrated-innovation/research/iot/index.html
9. Seymour, E., Hunter, A., Laursen, S. L., Deantoni, T., 2004, *Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study*, Science Education, 88, pp. 493-534
10. Abraham, S. (2016, June), *Using Internet of Things (IoT) as a Platform to Enhance Interest in Electrical and Computer Engineering*, Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.27149