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Preparing Undergraduate Engineering Students for the Internet of Things

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Dr. Samuel Dickerson is an assistant professor at the University of Pittsburgh Swanson School of Engineering. His general research interests lie in the area of electronics, circuits and embedded systems and in particular, technologies in those areas that have biomedical applications. He has expertise in the design and simulation of mixed-signal integrated circuits and systems that incorporate the use of both digital and analog electronics, as well as optics, microfluidics and devices that interface to the biological world. Dr. Dickerson also has a strong interest in enhancing undergraduate engineering education, and investigates new and innovative methods for improving the learning experience for electrical and computer engineering students.

Preparing Undergraduate Engineering Students for the Internet of Things

Abstract

Designing technology that will be part of the Internet of Things (IoT) requires knowledge from a broad spectrum of technical areas including analog and digital communications, information theory, networking protocols, microcontrollers and electronics, electromagnetics, and more. That breadth of subject matter runs counter to the increasingly narrow focus of Electrical and Computer Engineering programs and enrolling in courses that cover that span is often not practical for students. In trying to prepare students for the IoT, some questions that arise are: Which topics should be selected and where in the curriculum should those topics be presented to them? In what context do we present the topics to them? Also, how should we teach students about IoT in a way that is accessible, while maintaining enough depth of coverage that students have confidence in their ability to contribute to the future of the field? We've addressed these questions by revamping our introductory computer networking course, gearing all of the selected topics towards the IoT. Our approach is to take the students through the evolution of wireless networks past and present, starting from early radio communication and cellular networks, to medium and short range wireless computer networks and then to active and passive RFID networks. Each specific network type is not covered extensively, but rather a few key technologies from each network are selected and covered in depth, thereby creating a conceptual "toolbox" of IoT techniques and methods for the student. Along the way, topics typically not included in traditional networking courses, but important to the IoT, such as microcontroller interfaces, antenna design and RFID energy harvesting principles are introduced to the students. In this paper, a detailed overview of this newly developed course and its content is presented. In addition, we show how the structure of the course makes it especially well-suited to address one of the more challenging ABET student outcomes to assess, outcomes dealing with the impact of engineering solutions in a global and societal context. Finally, the degree to which we are achieving our desired learning objectives is evaluated using the results of student opinion surveys and a direct assessment of student work.

1. Introduction

The arrival of the Internet of Things (IoT) has brought about a world where the everyday objects we interact with, ranging from health monitoring devices to kitchen appliances and even toys, are embedded with intelligence and the ability to communicate over a network. The growth of IoT has been tremendous and it is estimated that in the near future the amount of networked "things" will number in the tens of billions[1]. Preparing undergraduate engineering students to be participants in this burgeoning subject area presents a unique challenge as the IoT is only vaguely defined itself. Designing technologies that will be part of the IoT requires knowledge from a broad spectrum of technical areas including analog and digital communications, information theory, networking protocols, microcontrollers and electronics, electromagnetics, and more. That breadth of subject matter runs counter to the increasingly narrow focus of

Electrical and Computer Engineering tracks and programs where enrolling in courses that cover that span is not practical for students.

We've addressed these questions by revamping our introductory computer networking course, gearing all of the selected topics toward the IoT. Our approach is to take the students through the evolution of wireless networks past and present, starting from early radio communication and cellular networks, to medium and short range wireless computer networks and then to active and passive RFID networks. Each specific network type is not covered extensively, but rather a few key technologies from each network are selected and covered in depth, thereby creating a conceptual "toolbox" of IoT techniques and methods for the student. Along the way, topics typically not included in traditional networking courses, but important to the IoT, such as microcontroller interfaces, antenna design and RFID energy harvesting principles are introduced to the students.

It has been recognized that the growing field of IoT will require an equally growing workforce consisting of capable technicians and engineers with broad skillsets[2]. However, at present suitable IoT-centric curricula that addresses this need are not readily availble[2] and to date very few IoT curricula have been proposed in the research literature. In some instances, it has been suggested to introduce IoT as a graduate course that focuses predominately on networking principles[3]. We desire to teach an IoT course that appeals to undergraduates, is comprehensive and accentuates core electrical and computer engineering skills that the students have already learned. One current trend in IoT education is to develop courses that focus primarily around microcontroller platforms[4,5] (e.g. Arduino, Rasberry Pi, etc). While the popularity and accessibility of these devices have contributed greatly to the Internet-of-Things, sole mastery of these technologies will not result in a student who can effectively create or evaluate new IoT solutions. Although embedded technology is a key component of the Internet-of-Things, the primary enabler is wireless technology. The only way to connect billions and billions of objects to the internet is wirelessly. Consideration to the fact that IoT devices are for the most part wireless devices is what drives the primary design decisions made in the development of IoT systems. It is for these reasons that we've made the decision to use wireless networks, starting from early mobile networks and then building up to RFID, as the foundation of our pedagogical approach to teaching students about the Internet-of-Things. In order to understand why the decision was made to use wireless technology and RFID as the student's foundation we can simply look at the history of the phrase "Internet-of-Things". The now popular phrase was coined in 1999 by members of the MIT Auto-ID center[6] who at the time were among the leaders in Radio-Frequency Identification (RFID) research. In predicting the impact that RFID would have on society, the ubiquitous world it would bring about and the enormous number of objects that would eventually be embedded with the ability to sense and transmit data, the eventuality of an "Internet-of-Things", or networked objects, was stated. RFID and the Internet-of-Things are tied closely linked to one another.

While the Internet-of-Things is already making impacts on society, its full potential is far from realized. At present, we enjoy such "things" as wearable healthcare sensors, smart power grids and networked appliances. However, it is not devices of that sort that will bring about the estimated tens of billions of connected objects. Not until our repertoire of "Things" routinely include mundane items such as clothing, milk cartons and livestock will we see how massive the IoT truly is. This pervasive IoT will be made possible by low-power RFID networks. When the IoT grows to that scale, there are a number of difficult engineering challenges that designers will have to face. What type of protocols will we have to use so that thousands of cattle in a field can share the wireless spectrum? How will we deliver power to the enormous amount of "smart" items on the grocery store shelves? What techniques will be used to ensure reliably enumerate the stockroom inventory in a noisy environment? Our goal is to prepare our students to be able to provide solutions to these types of challenges and be at the forefront of the coming technological change.

The rest of the paper is organized as follows: In the following section we present the course format, followed by a description of the main course topics in section 3. In section 4 we present results from direct and indirect assessments of the course and learning objectives. In the final section we conclude and provide a discussion of future work.

2. Course format

Our intended audience is junior/senior level students in both electrical and computer engineering programs. For a class of this type, teaching upperclassmen are desirable as they have the advantage of being able to see how many of the principles they learned earlier in their curriculums come together in the context of this single application. However, making such a class available to students from both programs does not come without cost. Electrical and computer engineering programs at many universities have bifurcated into two distinct programs. This division between electrical and computer engineering has the obvious advantage of enabling students to acquire an incredible amount of depth in their field but, that depth often comes at the expense of breadth of knowledge. For example, we have observed that rare is the case of a computer engineering student enrolling in electromagnetics or an electrical engineering student that pursues advanced embedded design courses. This can be problematic when it comes to teaching students about an application area such as the Internet-of-Things, as it involves the application of a wide variety of subject matter ranging RF propagation principles and communication theory to computer interfacing and microarchitecture. In order to make this course accessible, we maintain that no prerequisite other than the student having a junior-level status is required and any required concepts that are not common to the core curriculum of both programs is taught as needed.

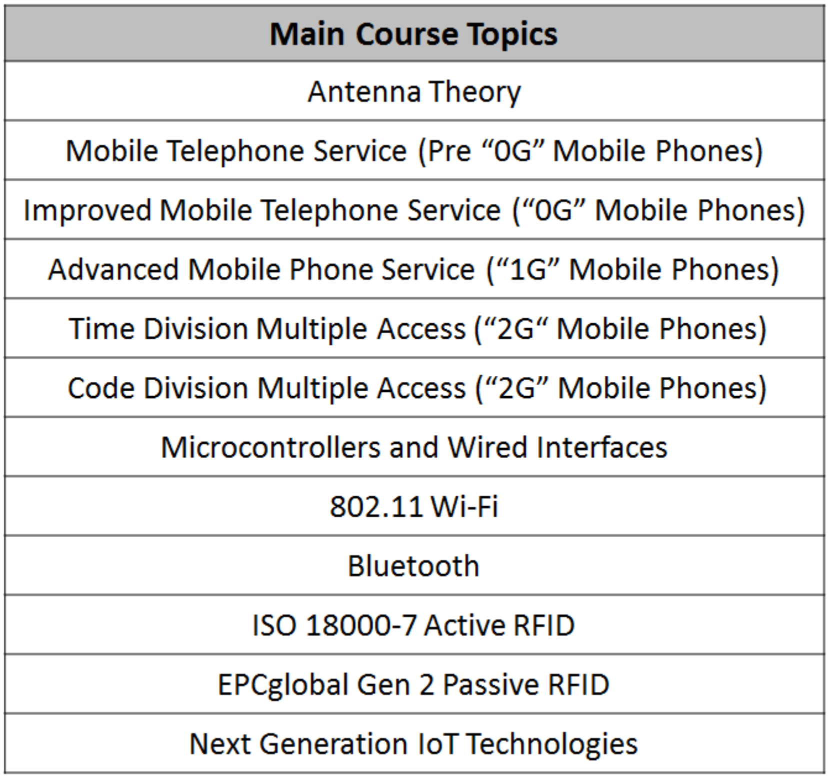
The class is structured as a lecture based course that meets on a weekly basis. We used the opportunity to revamp and update our computer networking course to develop this new offering, as the Internet-of-Things represents the future of networks. While the course's roots are in computer networks, the content is very different from any typical course offering. Our solution to this breadth/depth problem is to teach the students through the use of technologies that the students are familiar with. Specifically, from the very beginning the focus is on mobile wireless networks. Students are taken through the evolution of wireless networks, starting from the earliest mobile telephones and ending up at modern RFID. Any one network is not covered extensively. One of the primary themes of the course is that “everything that is old is new”. As we take the students through the progression of wireless technologies, we make sure to emphasize commonalities between successive generations. Our goal is for students to build a conceptual “toolbox” of techniques from the past that will be re-used in the future of IoT.

3. Course Content

Table 1 is a list of the primary topics covered in the course. Since the overarching theme for the course is wireless technology the course begins with the basics of wireless radio. We defer the discussion of modulation techniques and other system level radio aspects until later in the course. The focus at this early stage is on the design of antennas, which is new material for the majority of computer engineering students. The discussion of antennas we present goes into much further depth than what would be found in a typical networking course[7]. Topics such as antenna geometries, gain, polarization, frequency selectivity, emission patterns and energy transfer are discussed. One of the most important analytical tools that students obtain in this part of the course is the Friis transmission equation, an expression that provides an abstracted model of the power received by an antenna. This expression highlights the relationship between received power, frequency, distance and antenna parameters. These discussions lay the groundwork for understanding the organization and architecture of all subsequent wireless networks discussed as well as the basis for energy harvesting techniques used in passive RFID standards.

The first network examined is the mobile telephone service (MTS), the first mobile phone serviced offered in the United States and an early precursor to cellular networks. This network serves as the students’ first example of using air as a medium for communication. In examining the early MTS network students learn that the RF spectrum is a shared resource that has to be divided up into channels, and allocated. The MTS network had only 3 available channels making it very costly. It is with this network that students first learn one of the fundamental limitations of wireless networks, that the range of available frequencies and the ability to discriminate frequencies within that range limits the number of “users” of the medium. Later on students see that this same limitation occurs in future short range networks, except “users” are interchanged with “devices”.

After an examination of MTS, students are then in a position to understand the fundamental goal of and motivation for successive mobile wireless generations: Providing more “users” with access to the communication medium. This leads to the next network, the Improved Mobile Telephone Service (IMTS). IMTS was one of the early attempts to solve the problem of efficient utilization of the spectrum. It is with IMTS that students see that by reducing the transmitted power of a “basestation” we can reduce its geographical coverage area and increase the number of users by separating them spatially and by frequency. Later in the course when the students examine RFID, they see how the basestations of IMTS, and of the other networks we subsequently go on to examine, are analogous to RFID readers that transmit signals to devices within a coverage area. Another concept that IMTS introduces is that of Frequency Shift Keying (FSK), a RF modulation scheme for representing information. IMTS used the presence or absence of specific frequency tones to indicate states, a technique re-used by many future technologies. The final concept introduced by IMTS is the idea using a network protocol or rules for sharing the medium and in-band signaling, the transmission of information and control signals within the same bands.



Main Course Topics
Antenna Theory
Mobile Telephone Service (Pre “0G” Mobile Phones)
Improved Mobile Telephone Service (“0G” Mobile Phones)
Advanced Mobile Phone Service (“1G” Mobile Phones)
Time Division Multiple Access (“2G“ Mobile Phones)
Code Division Multiple Access (“2G” Mobile Phones)
Microcontrollers and Wired Interfaces
802.11 Wi-Fi
Bluetooth
ISO 18000-7 Active RFID
EPCglobal Gen 2 Passive RFID
Next Generation IoT Technologies

Table 1. List of Main Topics Covered in Course

After IMTS, we move on to the first generation of cellular networks, the Advanced Mobile Phone System (AMPS). With AMPS, the students dig deeper into the concept of frequency reuse and the power/coverage area/user tradeoff. AMPS also presents the concept of out-of-band signaling, designating separate channels reserved for control of the network. The control channels of AMPS contained digital information and act as an introduction to digital communications. When examining the format of the data sent on the control channels, we teach the students the concepts of synchronization, framing, forward-error correction and other methods for data redundancy.

The final set of macro-scale networks examined are from the second generation of mobile phones. The core concept taught at this juncture of the course is the idea of how the transistion to completely digital communications, not only for control signals but also for voice, enabled more sophisticated schemes for sharing the medium. More specifically, we use this opportunity to introduce spread spectrum communication techniques, frequency hopping and the idea of chipping bits over time (Time-Division Multiple Access used in European standards) and by code (Code Division Multiple Access used in United States standards). After coverage of these topics we do not discuss specific technologies from the third and fourth generation of mobile phones, as they are mostly more and more sophisticated digital communication techniques that are beyond the scope of the course and not as useful to learning the basics of RFID.

At this point in the course we make a switch from discussion of wireless networks and divert our attention to micro controllers and serial interfaces. Our reasoning for inclusion of these topics is two-fold. First, Internet-of-Things devices often make use of some sort of an embedded controller and sensors. These sensors often communicate with a host controller using a serial interface such as SPI or I2C. Coverage of these topics are not always covered in the core of electrical engineering curriculums and student knowledge coming into the course was observed to vary depending on prior electives. The second reason why these topics are included in a course that leads up to RFID is that in many ways the wireless medium is essentially equivalent to a single wire connecting a transmitter and receiver. As such, students see how data can be framed, transmitted serially and synchronized when there is an absence of a shared timing reference.

After wired interfaces, we get back into a discussion of wireless networks by looking at lower-power, shorter-range networks such as 802.11 and Bluetooth.   With 802.11 we teach students the concept of medium access control and the handling of collisions in a wireless environment, concepts that are critical to understanding RFID protocols and machine to machine communication. 802.11 is also used as a platform to teach students additional modulation schemes such as Phase-Shift-Keying and Amplitude Modulation. With Bluetooth, students once again have chance to examine the effects of reducing power, master-slave communication and also see the re-use of frequency hopping techniques from earlier networks.

In the final part of the course, we examine specific RFID standards. The two that we look at are the ISO 18000-7 Active RFID standard and the EPCGlobal Gen 2 standard. We examine every aspect of these two standards with the student. At this point in the course, many of the similarities to previous wireless networks are evident after examination such as the techniques used for modulation (FSK), synchronization and collisions. We introduce the students to the organization of RFID networks, consisting of RFID tags and a reader (i.e. basestation).   A RFID device cannot “speak” unless it has first been spoken to by a RFID reader. This brings the student to learn about the RFID tag discovery process where the reader must send out a signal to awaken any tags in the field and tags respond with their ID. In discussion of the Active RFID standard, students learn about the need for maintaining a power budget as the devices are intended to be left unattended for extended periods of time. In our discussion of the Gen2 Passive RFID standard, we return to antenna design.   In this context, we not only see how the antenna is used for communication, but also energy harvesting. The students see that the same analyses used to examine cellular towers and mobile handsets can be reapplied to examine passive readers and tags. The course concludes with a discussion of the future of RFID, IoT and the course finale serves as an opportunity to give students future directions for studying IoT.

4. Assessment of Student Learning

In this section we provide the results of three assessments of the course. Two of the assessments are direct measures of student learning outcomes that were carried out by having the instructor evaluate samples of student work. For these direct assessments, rubrics were developed that isolated student performance on the specified outcomes. The rubrics used in the assessment of outcomes and corresponding evaluation results are independent from student grades. For the first assessment, the students' ability to design an Internet-of-Things solution to a real world problem was measured. In the second assessment, the students' level of attainment of ABET outcome (h), the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context, was measured. The final assessment presented is an indirect measure, student surveys that reflect their opinions on the course and their learning.

4.1 Assessment of Student Ability to Design an Internet-of-Things Solution

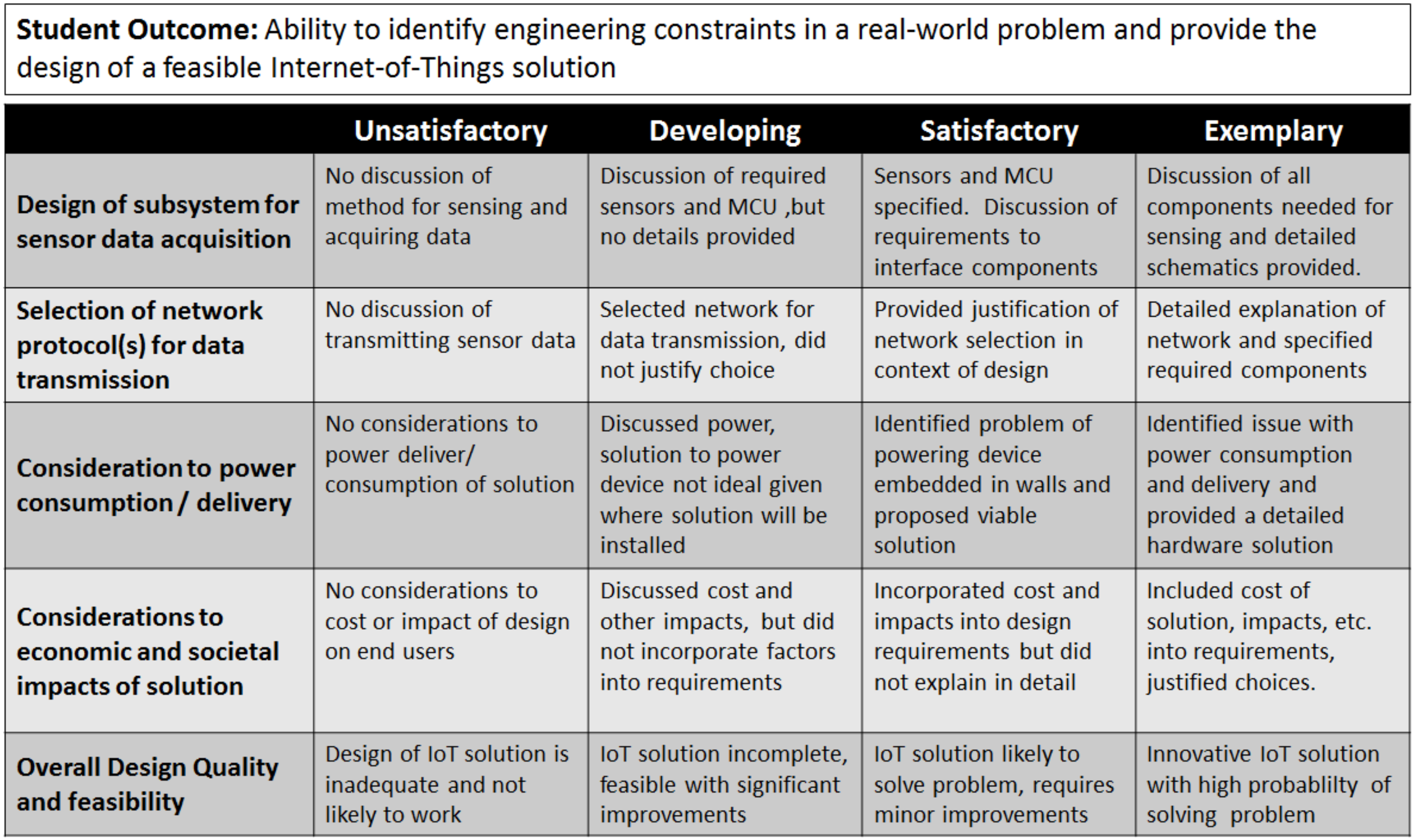
For this first measure, we collected data on the students' ability to identify engineering constraints in a real-world scenario and then provide a feasible Internet-of-Things solution. In this assessment, a single homework problem was assigned in which the students were presented with a problem and tasked with coming up with a pen-and-paper design. Around the time of the assignment of the exercise, the hospital that services our university was having a crisis: Several patients were infected with mold during their hospital stays and those infections contributed to their deaths[8]. The challenge faced by the hospital is that detecting the spread of mold can be very difficult, as it often grows in between walls, out of sight. However, early detection of mold in a hospital is critical to the safety of patients and of the utmost importance. Mold is the result of exposure to unwanted moisture for an extended period of time. The students were tasked with designing an IoT "smart wall" sensor that could detect whether or not conditions inside of the walls are conducive to growing mold. The assignment was given to the students as an open-ended exercise with very few explicitly stated constraints. In the assessment, our aim in part was to check the degree to which unsaid constraints would be identified by students and evaluate the solutions they proposed to get around those constraints. Figure 1 shows the full rubric used in this assessment. The outcome scored by the rubric was separated into five different performance indicators, evaluated at four levels of performance, ranging from unsatisfactory to exemplary.

The first performance indicator in this assessment is the student's ability to design a feasible subsystem for the acquiring data. In this case the relevant information to be measured is the moisture-levels between the walls. Figure 2(a) shows the evaluation results for this performance indicator. Most designs selected an off-the-shelf moisture sensor and a microcontroller unit (MCU) of some sort to process the data. In our rubric, a satisfactory design must have also provided a detailed discussion of the interfacing scheme for the moisture sensor and the MCU. The majority of students selected sensors that used one of the serial interfacing protocols discussed in class (i.e. SPI or I2C). Most of the students were exemplary in their demonstration of this performance indicator, going as far providing detailed schematics and datasheets to explain their design choices. A total of 86% of students (n = 23) had a performance that was at least satisfactory and no students performed unsatisfactorily in this regard.

Due to the fact that the sensor network they are designing will have to be placed inside of a wall, the next expectation was that students would provide a solution for wirelessly transmitting the information collected by their sensor. For this performance indicator, there is no clear best-choice of network and students employed a wide range of protocols. Student designs incorporated various short-range networks from among those we discussed in class (e.g. Bluetooth, 802.11, Passive RFID, etc.) and some that were not discussed but the students discovered on their own (e.g. Zigbee, WISP, etc.). Figure 2(b) shows the results of the assessment of their network choice. While one of any number of protocols could satisfy the design requirements, in the assessment we were looking to see that students provided a clear justification for their selection of network. For example, some students justified their network selection by pointing to the environment in which these sensors will be installed, a hospital. The observation was made by many students that in a hospital there are extra limitations on the use of the RF spectrum so as to not cause interference with medical equipment. Therefore, in their solutions they suggested the use of an 802.11 network that would make use of the existing hospital infrastructure. Other students selected Bluetooth or passive RFID, citing power consumption as their concern. Overall, 65% (n = 23) of students were evaluated as performing at a satisfactory level or above on this indicator.

One of the subtler constraints in this problem is that the sensors must be embedded inside of the walls. Therefore, a feasible solution must take delivery of power to the device and power consumption into consideration. Having to break apart walls every time a battery needs change is not a practical solution for a hospital. Considerations to this issue of power delivery and consumption was the basis of the third performance indicator. Students who achieved a satisfactory performance on this indicator identified this complication and proposed a reasonable solution to powering the device. Some students created a power budget that would lead to a device that could operate off of a battery for many years before having to be changed. In some of the better designs, proposed solutions incorporated RF-to-DC wireless energy harvesting components that allow for their device to be charged wirelessly, through the walls. A total of 61% of students (n = 23) made at least satisfactory provisions for delivering power to the design.

The final performance indicator for this assessment was a measure of the overall quality and feasibility of their design when considered in its entirety. All of the submissions would require improvements and various modifications in order to be actually successfully deployed. However, the majority of students (78%, n = 23) students developed a solution that was to likely work given minor improvements to the design. Table 2 summarizes the results of this assessment and displays the percentage of students who performed at a satisfactory or above level for each of the performance indicators.



Student Outcome: Ability to identify engineering constraints in a real-world problem and provide the design of a feasible Internet-of-Things solution

	Unsatisfactory	Developing	Satisfactory	Exemplary
Design of subsystem for sensor data acquisition	No discussion of method for sensing and acquiring data	Discussion of required sensors and MCU ,but no details provided	Sensors and MCU specified. Discussion of requirements to interface components	Discussion of all components needed for sensing and detailed schematics provided.
Selection of network protocol(s) for data transmission	No discussion of transmitting sensor data	Selected network for data transmission, did not justify choice	Provided justification of network selection in context of design	Detailed explanation of network and specified required components
Consideration to power consumption / delivery	No considerations to power deliver/ consumption of solution	Discussed power, solution to power device not ideal given where solution will be installed	Identified problem of powering device embedded in walls and proposed viable solution	Identified issue with power consumption and delivery and provided a detailed hardware solution
Considerations to economic and societal impacts of solution	No considerations to cost or impact of design on end users	Discussed cost and other impacts, but did not incorporate factors into requirements	Incorporated cost and impacts into design requirements but did not explain in detail	Included cost of solution, impacts, etc. into requirements, justified choices.
Overall Design Quality and feasibility	Design of IoT solution is inadequate and not likely to work	IoT solution incomplete, feasible with significant improvements	IoT solution likely to solve problem, requires minor improvements	Innovative IoT solution with high probablilty of solving problem

Figure 1. Rubric and performance indicators used to evaluate assessment of the students' ability to identify engineering constraints and provide a feasible Internet-of-Things based solution

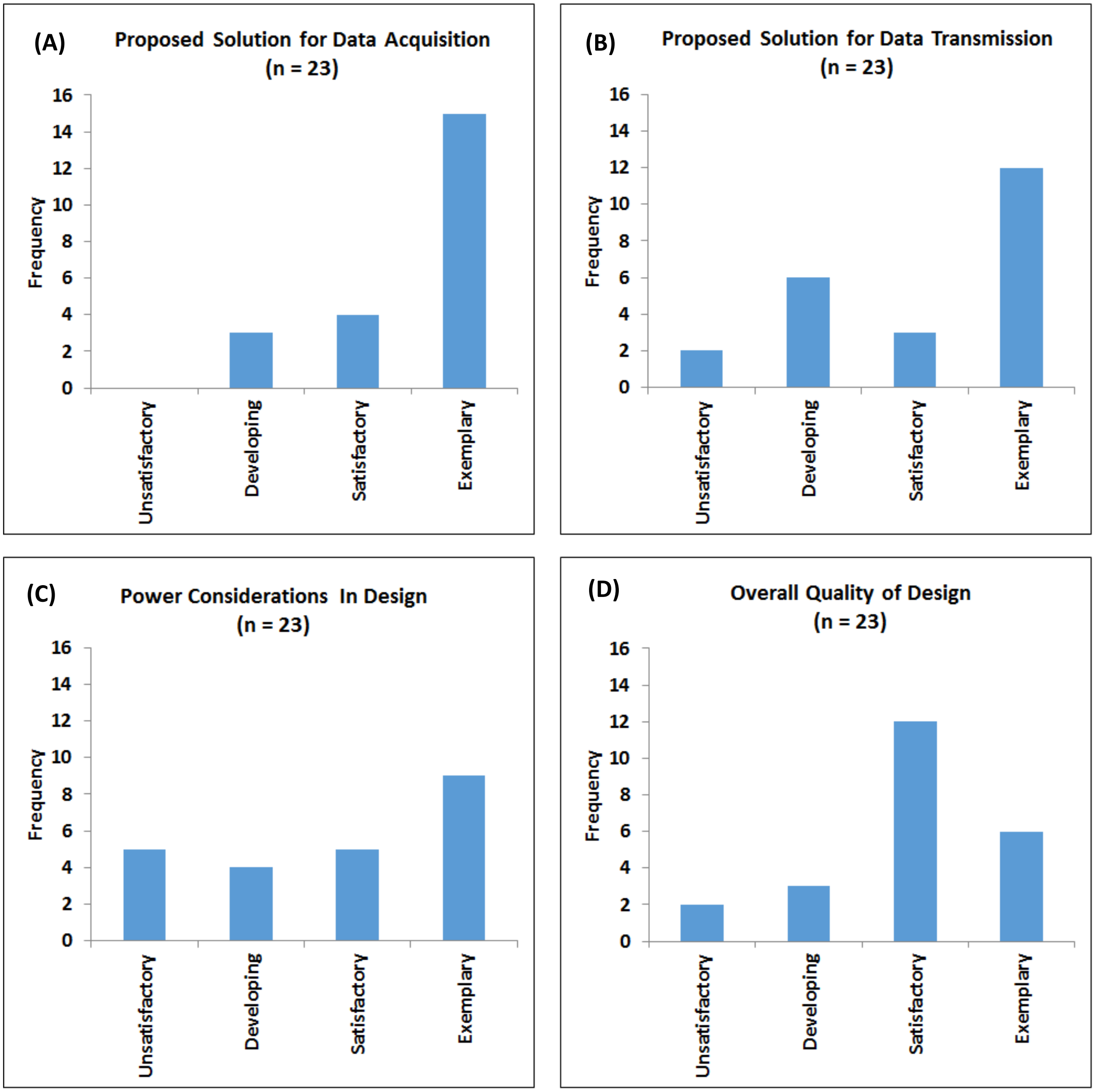
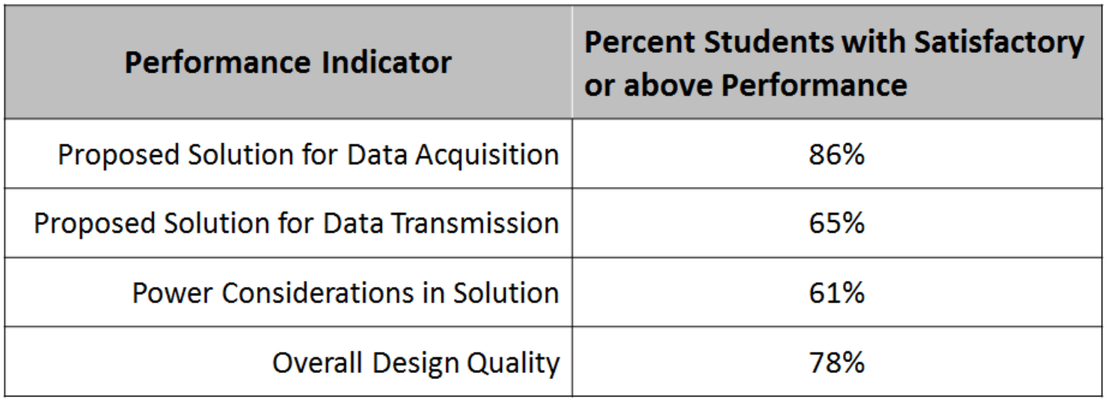


Figure 2. Results of IoT design assessment



Performance Indicator	Percent Students with Satisfactory or above Performance
Proposed Solution for Data Acquisition	86%
Proposed Solution for Data Transmission	65%
Power Considerations in Solution	61%
Overall Design Quality	78%

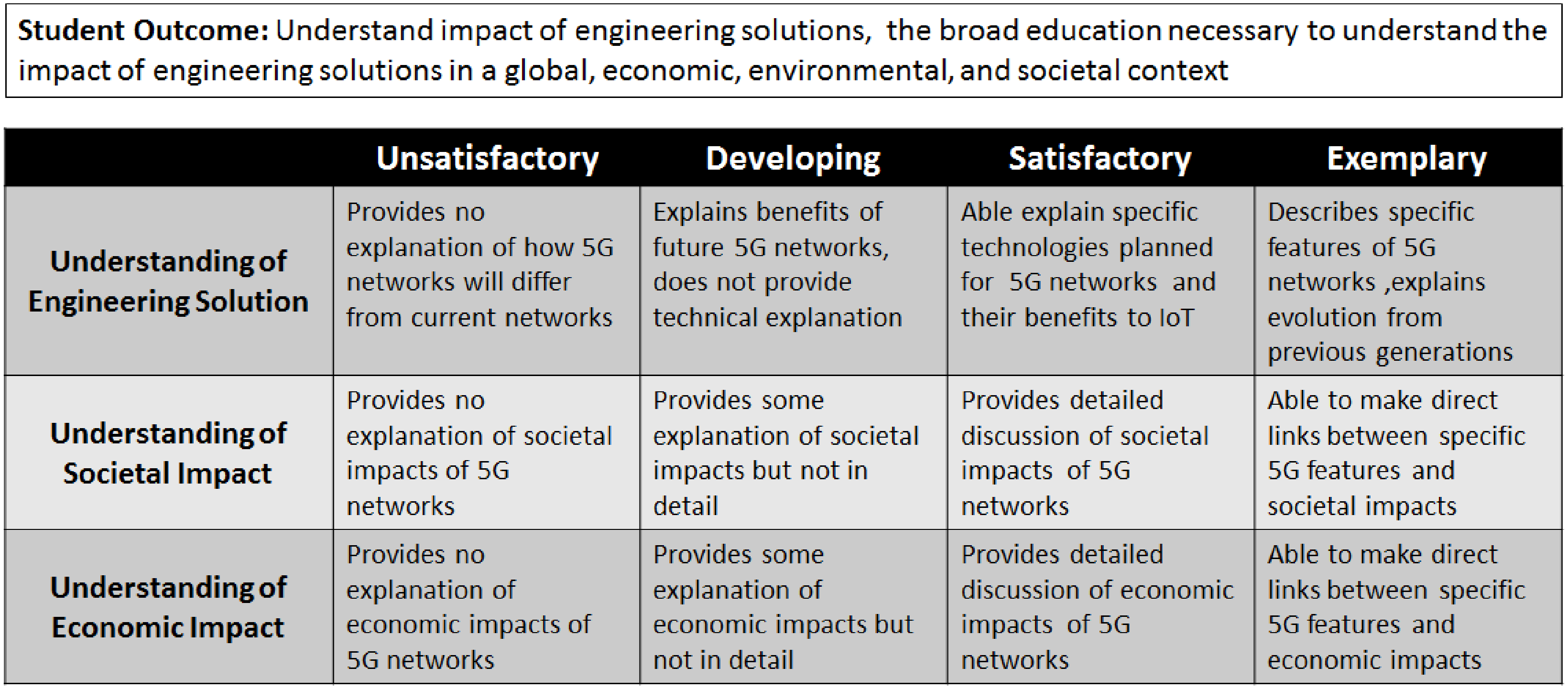
Table 2. Summary of IoT design assessment. Table displays percentage of students (n=23) that were evaluated as having satisfactory or above performance on the given indicator

4.2 Assessment of Students' Ability to Understand Impact of Engineering Solutions

The second direct assessment was carried out to measure the students' ability to understand the impact of engineering solutions in an economic and societal context. This assessment directly maps to ABET student outcome (h)[9]. This outcome can at times be challenging to measure. We feel that this course is particularly well suited to address the teaching of this outcome to students and for assessing it. Our interpretation of this outcome is that students who perform at a satisfactory level have the ability to identify specific, low-level, technological features of an engineering solution and then make one-to-one correlations between those features and impacts on society and/or economic factors. The engineering solutions focused on in this course (IoT) have tangible, observable benefits for people. Additionally, IoT solutions are often realized as consumer products that directly affect our economy.

In order to assess this outcome, the students were given homework assignments in which they were to write an essay that answers a single question: What are 5G mobile networks and how will they impact society? The fifth-generation of mobile networks has yet to be realized. The final specification defining what constitutes a "5G" wireless network is far from well-defined and will be debated over the years to come. One aspect that is generally agreed upon is that the driving motivation behind this next generation of wireless networks is the Internet-of-Things and the increased demands it will bring about. Examination of future 5G networks is well-suited for this course as it serves as a bridge between what they learned at the outset of the course, previous mobile wireless generations, and where the course concludes, RFID and the Internet-of-Things.

There was no discussion of 5G networks during class lectures. Our discussion of mobile networks ceases after briefly discussing some features of the third generation of cellular networks. Students were asked to independently research 5G networks and present their findings. Figure 3 shows the rubric we developed to assess this outcome. We selected three performance indicators. By making this an independent research assignment, we are able to evaluate the students' ability to understand a new, yet-to-be-realized engineering solution. The other two indicators are used to measure students' understanding of the societal and economic impacts.



Student Outcome: Understand impact of engineering solutions, the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

	Unsatisfactory	Developing	Satisfactory	Exemplary
Understanding of Engineering Solution	Provides no explanation of how 5G networks will differ from current networks	Explains benefits of future 5G networks, does not provide technical explanation	Able explain specific technologies planned for 5G networks and their benefits to IoT	Describes specific features of 5G networks ,explains evolution from previous generations
Understanding of Societal Impact	Provides no explanation of societal impacts of 5G networks	Provides some explanation of societal impacts but not in detail	Provides detailed discussion of societal impacts of 5G networks	Able to make direct links between specific 5G features and societal impacts
Understanding of Economic Impact	Provides no explanation of economic impacts of 5G networks	Provides some explanation of economic impacts but not in detail	Provides detailed discussion of economic impacts of 5G networks	Able to make direct links between specific 5G features and economic impacts

Figure 3. Rubric and performance indicators used to evaluate assessment of the students' ability to identify engineering constraints and provide a feasible Internet-of-Things based solution

Students were evaluated on a four-level scale ranging from unsatisfactory to exemplary performance. For the first indicator we looked to see that students demonstrated the ability to identify specific technological features of 5G networks. For example, some students only indicated that that 5G networks would be "faster" or provide more bandwidth, but did not explain any engineering solutions would make those improvements possible. Students' that performed at a satisfactory and above level pointed to and explained planned features that would make those advancements possible, such as MIMO, the use of millimeter wave frequencies, cognitive radio or the use of femtocells. Additionally, exemplary students displayed the ability to explain how those features evolved from previous generations. Many were able to make direct connections between these yet-to-be-realized features some of the techniques and methods from the past we learned in class. A total of 70% of the student population (n = 23) performed at a satisfactory or above level.

In assessing student understanding of social and economic impacts, the minimum requirement for obtaining a satisfactory level of performance was demonstration of the ability to correlate at least one planned feature of 5G wireless to a specific impact. For example, one student used his knowledge of the Friis transmission equation to explain how the use of the extremely high frequencies associated with millimeter waves will result in reduced-power, smaller coverage area cells, potentially enabling more frequency re-use. This student went on to discuss how this more efficient use of the spectrum permits for denser IoT networks that can be installed inside of future "smart" buildings, accommodating a vast number of sensors. The student concluded that by incorporating the use of such high frequencies into 5G networks, enabling the collection and transmission massive amounts of sensor data, more opportunities for economic growth will be created and that the lives of people around the world will be improved by the increase in efficiency of the buildings they reside in and increased access to information. Out of the student population assessed (n = 23), 78% demonstrated a satisfactory understanding of societal impacts, but only 22% demonstrated a sufficient understanding of economic impacts. This reveals that most students do have a good ability to understand the impacts engineering solutions have on society and people, but fail to recognize economic factors. As discussed in the final section, this deficiency will be addressed in future course offerings. Table 3 shows a summary of this assessment and displays the percent of students who performed at a satisfactory level or above for the three selected performance indicators.

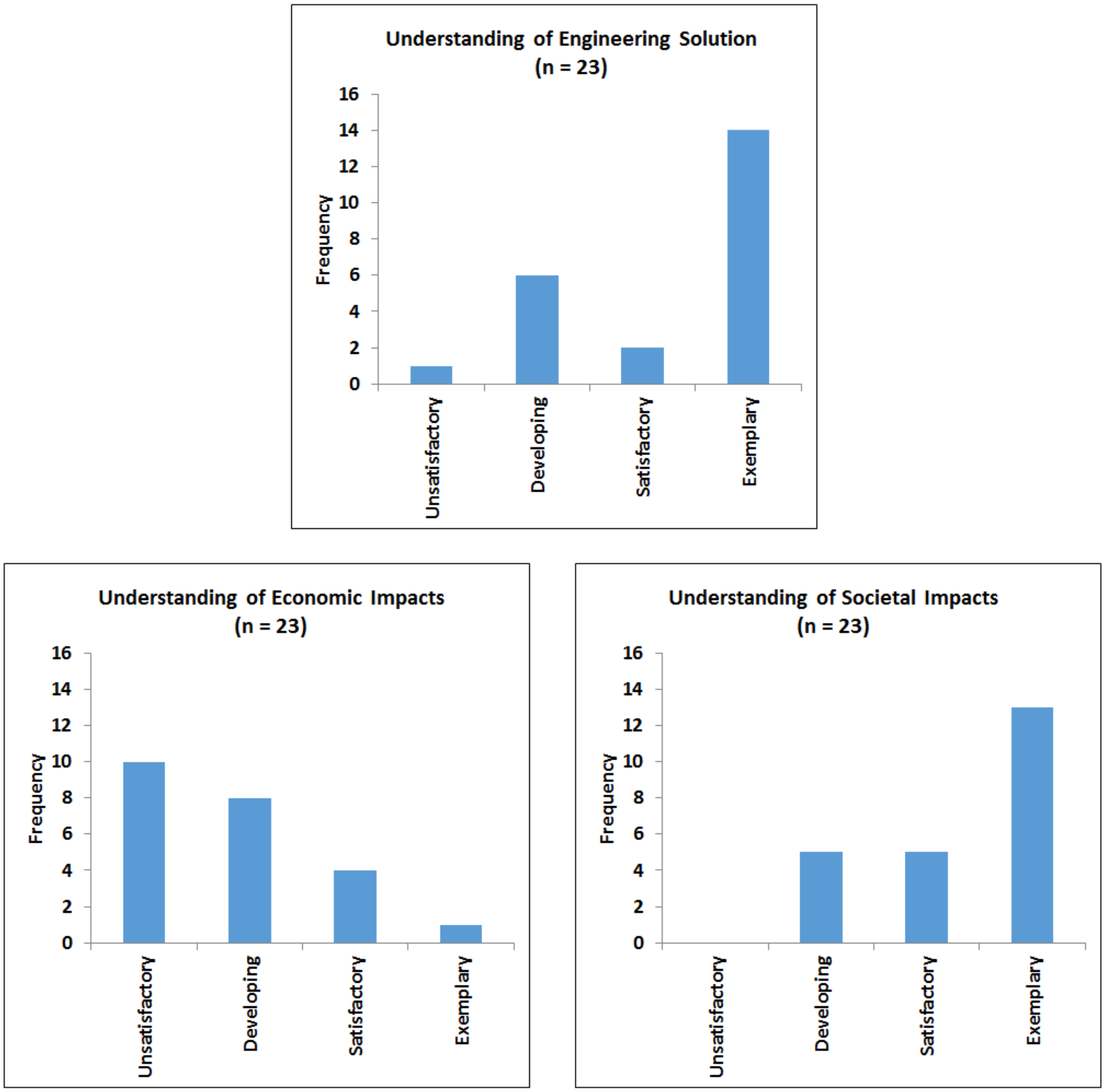
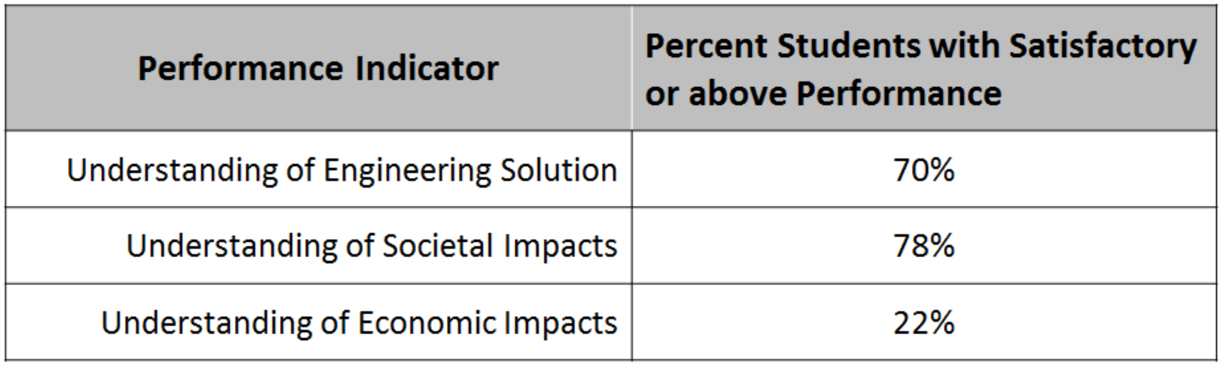


Figure 4. Results of assessment of student understanding of the economic and societal impacts of future 5G mobile wireless networks designed to support the Internet-of-Things



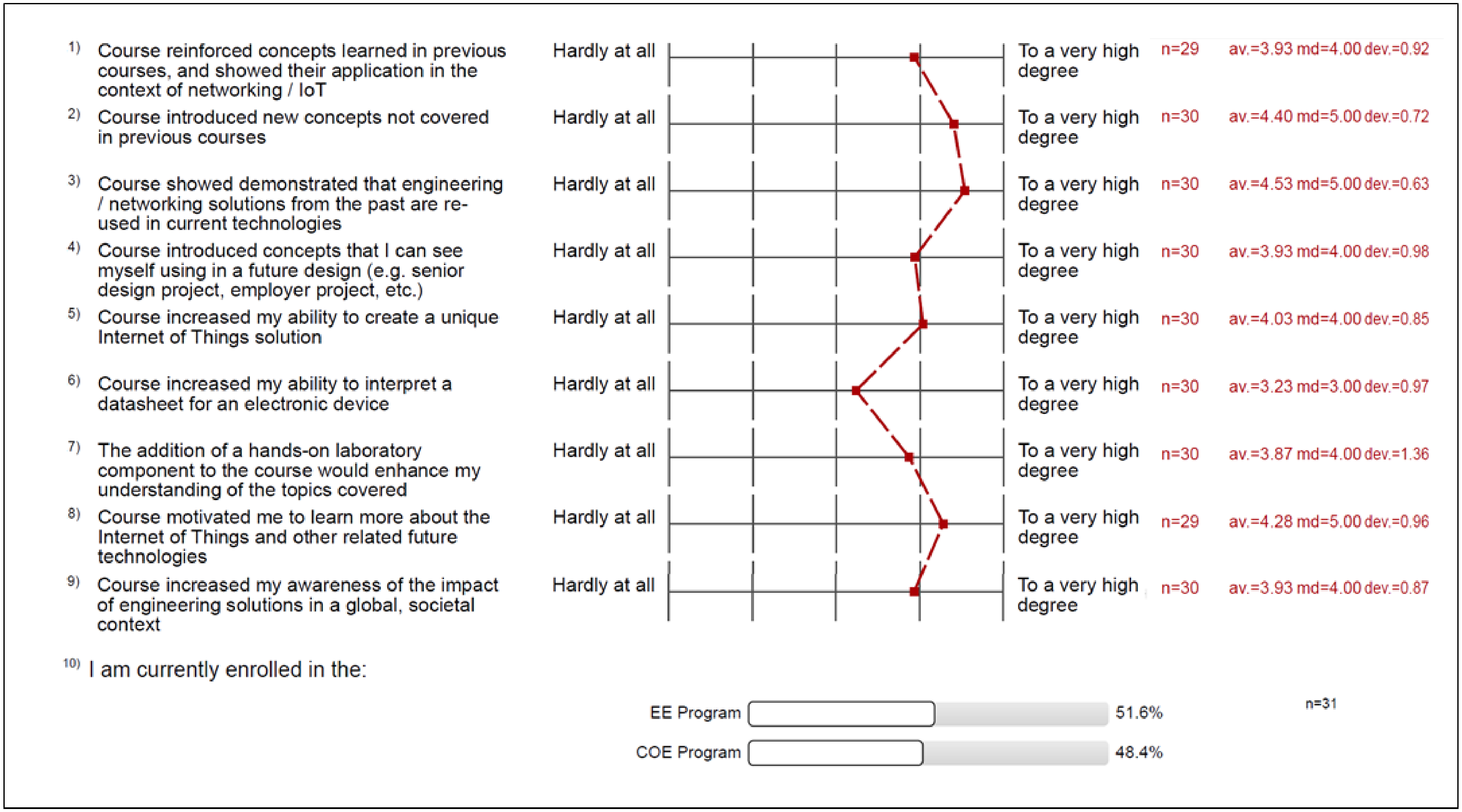
Performance Indicator	Percent Students with Satisfactory or above Performance
Understanding of Engineering Solution	70%
Understanding of Societal Impacts	78%
Understanding of Economic Impacts	22%

Table 3. Summary of societal and economic impacts assessment. Table displays percentage of students (n=23) that were evaluated as having satisfactory or above performance on the given indicator

4.3 Student opinion of course content and attainment of learning objectives

The final assessment is an indirect measure of student learning and a collection of their opinions about the course. This data was collected by way of a survey administered to the class. Figure 5 shows the questions included in the survey, as well as the sample size and survey results. The nine questions were answered by students on a 5-point Likert scale, measuring the degree to which they agreed with the provided statements.

The survey results show that the course struck a good balance between showing students the application of concepts they previously learned (question 1, av. = 3.93/5.00) and introducing them to new concepts (question 2, av. = 4.40/5.00). Since the distribution of students by enrolled program was almost evenly split (question 10), 52% from the electrical engineering program and 48% from our computer engineering program, we considered the results of questions 1 and 2 to be very positive outcomes. Those results show that we were successful in striking a right balance of breadth and depth, introducing new material to both audiences, while at the same time reinforcing what they already learned in their separate, but different curriculums. The survey results also show that the students picked up on one of the recurring themes of the course, that engineering solutions from wireless networks past are frequently reused in current and future technologies (question 3, av. = 4.53/5.00). It was the opinion of the students that the course was successful in teaching them how to design IoT-based solution to a problem (question 5, av. = 3.93/5.00) and many felt (question 4, av. = 3.93/5.00) that there was a high likelihood they would directly apply what they learned in a future project (e.g. senior capstone project, employment, etc.). Finally, the survey shows that students left the course with an increased enthusiasm for the Internet-of-Things as well as the desire to continue study of this topics after the conclusion of the course (question 8, av. = 4.28/5.00).



1)	Course reinforced concepts learned in previous courses, and showed their application in the context of networking / IoT	Hardly at all	To a very high degree	n=29	av.=3.93 md=4.00 dev.=0.92
2)	Course introduced new concepts not covered in previous courses	Hardly at all	To a very high degree	n=30	av.=4.40 md=5.00 dev.=0.72
3)	Course showed demonstrated that engineering / networking solutions from the past are re-used in current technologies	Hardly at all	To a very high degree	n=30	av.=4.53 md=5.00 dev.=0.63
4)	Course introduced concepts that I can see myself using in a future design (e.g. senior design project, employer project, etc.)	Hardly at all	To a very high degree	n=30	av.=3.93 md=4.00 dev.=0.98
5)	Course increased my ability to create a unique Internet of Things solution	Hardly at all	To a very high degree	n=30	av.=4.03 md=4.00 dev.=0.85
6)	Course increased my ability to interpret a datasheet for an electronic device	Hardly at all	To a very high degree	n=30	av.=3.23 md=3.00 dev.=0.97
7)	The addition of a hands-on laboratory component to the course would enhance my understanding of the topics covered	Hardly at all	To a very high degree	n=30	av.=3.87 md=4.00 dev.=1.36
8)	Course motivated me to learn more about the Internet of Things and other related future technologies	Hardly at all	To a very high degree	n=29	av.=4.28 md=5.00 dev.=0.96
9)	Course increased my awareness of the impact of engineering solutions in a global, societal context	Hardly at all	To a very high degree	n=30	av.=3.93 md=4.00 dev.=0.87

10) I am currently enrolled in the:

EE Program	51.6%	n=31
COE Program	48.4%	

Figure 5. Student Opinion Survey of Course Content and Attainment of Learning Objectives

5. Discussion and Future Work

The assessment results of section 4 show that the course was successful in providing students with a solid technical foundation for the Internet-of-Things. By way of our approach, teaching students techniques commonly used in IoT using familiar technologies from previous generations and highlighting commonalities to the current state-of-the-art, we prepare them to understand whatever the future of the Internet-of-Things has to offer.

Our assessment results also show that there is room for improvement in future offerings of the course. In order to enhance the ability of students to realize practical, feasible IoT solutions, one area in need of improvement is in teaching students about the importance of making considerations to power. While 61% of students were observed to perform at a satisfactory level in regard, the desire is for that percentage to be much higher, as power consumption is critical at all stages of design in IoT applications. In the future, we will address this by spending even more time discussing specific devices that implement the protocols and techniques discussed. Additionally, we will spend time examining datasheets for specific devices that demonstrate how decisions made at the system level impact power consumption and delivery at the implementation level. Another deficiency observed was in student understanding of the economic impacts of engineering solutions (22% above satisfactory). The student opinion survey (Figure 5, question 10, av. = 3.93/5.00) reveals that students feel that the course is sufficient in teaching the impacts of engineering solutions in a societal and economic context. That opinion proved true when compared to the assessment of understanding of societal impacts (78% above satisfactory). However, the direct assessments show that when social and economic impacts are teased apart, there is a large disparity in the understanding of the two. In the next iteration of the course we will address this lack by including a discussion of the economic drivers behind each network and technology examined in class and not for just a select few.

The most significant future modification we plan to make is the addition of a complementary laboratory component. While we feel that the lecture-only, pen-and-paper format of the course is a strength, there are many lessons and design principles that are better taught in a hands-on, active learning environment. This sentiment is supported by the student opinion surveys (Figure 5, question 7, av. = 3.87/5.00). The course is successful at providing students with diverse backgrounds a good theoretical foundation and teaching them the basics of IoT design. The addition of lab component would only enhance those new skills and further add to their growing preparedness for the Internet-of-Things.

6. Acknowledgments

The author of this paper would like to acknowledge the contributions of the late professor Marlin Mickle to this work, a pioneer in RFID and Internet-of-Things education.

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