Engineering STEM: Using IoT and Energy Management to Build Interest in Engineering at the Secondary Education Level

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Abstract

For the past two summers, faculty in the Electronic Systems Engineering Technology Program at Texas A&M University have been funded by NSF to develop and deliver STEM workshops to educators at the secondary level. The focus of these workshops has been in integrating four important engineering topics: engineering design principles, additive manufacturing processes, energy management and Internet of Things (IoT). This work, together with the partnerships that have been developed between the Colleges of Engineering, Education and Science, have resulted in a unique capstone design project. The project includes students in the Electronic Systems (ESET) and the Mechatronics (MXET) programs in the College of Engineering paired with students in the College of Education and the College of Science. Based on the identified need for both resources and curriculum, the project team is engaged in the design and development of a one-quarter scale, four room "house" that is fully instrumented to be monitored and controlled remotely as a IoT system. As this resource is being designed and constructed by ESET and MXET capstone team members, students in Education and Science are developing curriculum modules that can be readily integrated into current math, science, and engineering courses at the secondary level. The IoT house is expected to be centrally located at Texas A&M or other accessible locations and used remotely via the Internet by multiple groups of 8-12 grade students. The project is scheduled to be completed by December 2018 with curriculum to be field tested in the Spring 2019 semester. This paper will provide introductory and background information on the genesis of the project, the establishment of the interdisciplinary team, an overview of the IoT house, a demonstration of its operation, and conclusions and next steps for the expanded use and further curriculum development at the secondary level.

Introduction and Background

It is widely recognized there is a significant lack of understanding and desire to pursue careers that involve science, technology, engineering and mathematics (STEM) by a large part of the population in the US today. This directly translates to many students at the primary and secondary educational levels often avoiding the consideration of STEM-related careers after graduation or even opportunities to further their knowledge in advanced mathematics and science while still in school. To ensure that the United States remains competitive on a global scale, it is important that this trend be changed. One way to do this is by using authentic engineering and technology design experiences[1] to excite teachers and students and help them see the value and relation of STEM fields to their everyday lives. In fact, there is a growing trend of incorporating engineering and technology principles in both primary and secondary educational objectives at the state and national levels.[2,3] However, it is also important that today's teachers be given sufficient engineering and technology skills and background so they can develop appropriate curriculum and deliver it with confidence.

Faculty members in engineering technology (ET) are uniquely positioned to do this. Due to the experiential nature of engineering technology education and the focus on hands-on applications, most ET faculty members have expertise in creating curriculum that bridges the gap between STEM theory and real-world application. These skills can be used to make engineering and technology education more accessible for primary and secondary teachers and their students. In fact, the faculty members in the Electronic Systems Engineering Technology Program at Texas A&M University have been doing this for many years through the development and delivery of junior high and high school workshops that involve robotics, embedded hardware/software development, additive manufacturing and project management principles. These workshops are offered both during the summer and the normal school year and have been well received by many local and regional schools.

These successes led the faculty to propose a project to the Innovative Technology Experiences for Students and Teachers (ITEST) program sponsored by the National Science Foundation (NSF) focused on increasing teacher understanding and use of engineering design through the development and delivery of authentic experience-based curricula. The project has as a goal of promoting junior high and high school student interest, skills, knowledge, and career aspirations in engineering through authentic engineering design activities related to building automation. This goal is being accomplished through several objectives:

- Increasing teacher use of engineering design and product development process
- Increasing student understanding of engineering design and engineering careers
- Stimulating student interest in math and science
- Increasing high school student career interest and opportunities in building automation
- Promoting parental understanding of engineering careers and technological development

One of the unique aspects of this project, entitled ”Connected STEM - Promoting STEM Education through Connected Devices and Building Automation,” is that the faculty decided early on to focus on very specific engineering applications that could be easily identified with and understood by the students and teachers. To this end, three areas were chosen:

- Building automation: The ubiquity of building automation systems in everyday lives ensures that most people easily understand the use of these systems. In addition, it allows teachers to use their schools and their students' homes as living laboratories when developing curriculum.
- Additive manufacturing: The amount of press and information surrounding 3D printing makes this area prime for peaking student curiosity and their desire to learn.
- Connected devices: The Internet of Things (IoT) is another transformational technology that is widely used in industry[4] and that lends itself to exciting applications in the classroom. It is also easily integrated with building automation and students' smart phones allowing them to interact with any applications they develop.

To achieve the stated objectives, the ITEST project uses a multi-prong approach including:

- the offering of student summer camps each summer. These camps allow the faculty to vet ideas and gauge their impact on typical 6th-12th grade students before presenting them to teachers.
- the delivery of teacher workshops each summer. These workshops are two weeks in duration and have several objectives: to educate the teachers on engineering design, building automation, additive manufacturing and connected devices; to support their development of engineering-based curriculum for use during the school year; and to give them opportunity to try out their curriculum on typical students.

- the support of teachers during the year as they use the technologies and curriculum developed during the workshop in their courses. This not only includes technical support but also the identification of relevant industry speakers that can speak to STEM careers in their classes and the support of an industry night that allows contact with students and their parents.
- the joint development of a dual credit course with a regional two-year college. The course is offered to high school students who have developed an interest in learning more about STEM-related careers, especially in the areas of building automation, additive manufacturing and connected devices.

The ITEST project is now in its second year. The teacher workshop and student summer camps have each been offered twice. In addition, the teachers from the first workshop have had a chance to implement their ideas in the classroom during the 2017-2018 school year. From these experiences, it has become clear that while the teachers seems to grasp the technology, they have had difficulty using it to teach their learning objectives. Specifically, it was hoped that teachers could develop application platforms around which to center their curriculum on their own but this proved to be difficult, especially for teachers who focus on math and science courses. For this reason, the faculty quickly decided that the development and implementation of a building automation and IoT educational platform that could serve as a focal point for their curriculum development was needed.

To do this, different approaches were examined. First, the use of modeling and simulation environments for building automation that have previously been developed for educational and industrial use were considered.[5,6] However, it was quickly decided the level of abstraction involved with simulation was contrary to the goals of the project. Through previous experience working with K-12 students, the faculty has determined that hands-on experience with actual technology is the best way to excite young students and increase their interest level. A quick literature search showed examples of existing small-scale building automation systems that have been previously developed for use in education[7]. Ultimately, the faculty determined that it would be easier to develop a system in-house rather than to convert an existing system for use with the IOT technology currently being used.

Over the last two years, three parallel development efforts have been undertaken to create a scale building automation environment that teachers could use in the classroom. The first effort resulted in a very simple multi-room home that teachers could use as the focal point for their curriculum development. While this approach was easy to implement and was inexpensive, it still required the teachers to develop technology in order create an operational building automation system. The second approach created a similar small-scale house but included lighting, air ducts and a simple commercial-off-the-shelf based system for heating and cooling. This system was more complex and expensive. It also required more knowledge on the teacher's part in order to maintain it over the school year. The third solution took a more unique approach. It involved the creation of a quarter-scale home with a functional building automation system that was fully instrumented and could be accessed, controlled and observed though the internet. This allows the system to be housed at the university, maintained by the faculty and used remotely by teachers from their various locations. All three of these concepts were presented to the teachers in the most recent summer workshop. For obvious reasons, the teachers all gravitated to supporting this third concept.

The balance of this paper focuses on the development and implementation of this third building automation and IoTsystem. It should be noted that while this is a work-in-progress, system development is complete and the faculty in the College of Engineering are currently working with faculty and students in the College of Education to develop curriculum that leverages the IoT house and can be used in next year's teacher workshops.

Establishing the Research Team

Because of the interdisciplinary nature of the project, the research team is composed of faculty and individuals from multiple colleges at Texas A&M University as well as faculty from a regional two-year college and a local company with expertise in offering summer camps. Due to the primary focus areas of the project and the need for expertise in engineering design, four members of the team, including the principle investigator, are from the Engineering Technology and Industrial Distribution Department in the College of Engineering. Their primary responsibility includes the development and delivery of all workshop material involving engineering design, building automation, additive manufacturing and connected devices. These team members also leverage their contacts with industry to secure needed equipment as well as guest speakers to support the teachers during the school year.

To support the teachers with developing curriculum for use in their classrooms, two members of the team are from the College of Science and the College of Education. Their role is to help the teachers integrate engineering and technology education into the regular curriculum. After the first year, it was decided to focus on teachers who were responsible for teaching math and science at the junior high school level. This ensures early contact with students and a better ability to influence their potential career path.

The remaining members of the team have several independent functions. First, a local firm with expertise in delivering summer workshops is responsible for creating and delivering multiple workshops that can be used to "test drive" concepts and ideas before presenting them to the teachers. Second, a representative from a local community college is responsible for developing a dual-credit course that can be offered at high schools. The purpose of this course is to ensure that students impacted by the project and with a desire to learn more, can earn college credit in a STEM course and move them along a path towards a STEM career. Finally, a firm with expertise in assessment and evaluation was brought on to continuously monitor the project and allow for real-time changes to maximize the potential for success. It should also be noted that several engineering technology undergraduate students were hired to support curriculum development and delivery. In fact, these students were the primary drivers in developing the three platforms discussed previously.

Model Building Automation and IoT Houses

Based on interaction with the first cohort of secondary level math and science teachers, the research team concluded that more hands-on manipulatives would be required to support a higher level of engagement necessary to bring IoT-based building automation and energy management into their classrooms. Specifically, the team agreed that having a building automation and IoT house that could be used by the teachers would significantly improve and accelerate the engineering concepts and processes. With this goal in mind, the team looked at several implementation paths to create such structures. The ESET, MMET and MXET programs used their Capstone Design Project students to design, implement and document prototypes of these structures. These included three different levels of capability and associated level of technology and cost:

1. Small, student-built version
2. Medium, classroom version used by all students
3. Large, full-featured version that was remotely accessible via the internet

Version 1 – Small, student-built house

The first version of the IoT House was design so that a small team of students could build their own structure. This structure was approximately 15"x15"x15" in size and was constructed primarily from form board readily available from a local hardware store. The pieces for the walls and roof were cut and glued together so that the house could be instrumented with the IoT devices that the teachers received during the summer workshop. These devices can measure a number of environmental parameters including temperature, humidity, pressure and light intensity using a Texas Instruments CC3200 Launchpad and a Boost XL-Sensor Pack. The CC3200 can then upload these data to a Cayenne dashboard for display. With the addition of a dual H-Bridge module, the CC3200 can also control a number of output devices including motors and lights.

During the second summer session, all teachers were able to use the provided materials and assembly guide to construct and instrument their small form factor IoT Houses. Although functionally limited, the low cost and ease of construction makes this design suitable for lower-level courses or where small teams of students would work together to build the structure. With this additional resource, the teachers were able to be more innovative in their plans to incorporate IoT-based energy monitoring and building automation into their math and science courses than the first summer cohort.

Version 2 - Medium, classroom version used by all students

Simultaneously with the design of Version 1, a second capstone design team was tasked to create a medium scale IoT House that focused more on the monitoring and control of the structure. The model that this team created was intended to be a "one-of" resource that could be built for a classroom where multiple student teams would have the ability to instrument, monitor and control more aspects of the structure. For example, this design included a fully functional heating and air conditioning system with associated ducting and vents to control air flow into and out of each of three rooms. The approximate size of this structure was 36"x24"x15" and included windows, doors, lights, and fans. Complete assembly, wiring and setup for this structure were provided by the Capstone team.

Although the teachers were quite impressed, they also believed that the level of complexity and cost of this structure exceeded their comfort zone. Based on this feedback a third team was tasked to enhance the overall design of the house and to make it fully accessible to secondary level math and science teachers via the Internet

Version 3 - Large, full-featured version that was remotely accessible via the internet

Based on the design of the previous two IoT Houses, the third Capstone team was tasked to design and equip a 1:4-scale home that could be built on a single 4'x8' plywood base.[8] It was required that Version 3 would include a number of features available in current houses to monitor and control environment aspects of the house. Using a 1:4 scaling, the design replicated a real house (apartment) that was 16'x32' with 12' (4'x8'x3') walls. As shown in Figure 1, the house was built on a specially design rolling cart that allowed for the HVAC to be installed out of the way, beneath the house and also accommodate much of the wiring and ducting necessary for the home.

Figure 1. IoT House - 1:4 Scale

The scale model includes

- Two types of roof constructions
- Multiple insulation methods
- HVAC system
- Four rooms
- Three doors – one remotely lockable
- Seven windows – with remotely controllable blinds
- Lights and Fans
- Motion actuators and detectors
- Four cameras – three inside, one outside
- External heating capability

Figure 2 depicts an example of the various monitoring and control systems that are included in the design, and Figure 3 shows the overall structure layout of monitoring and control capabilities.

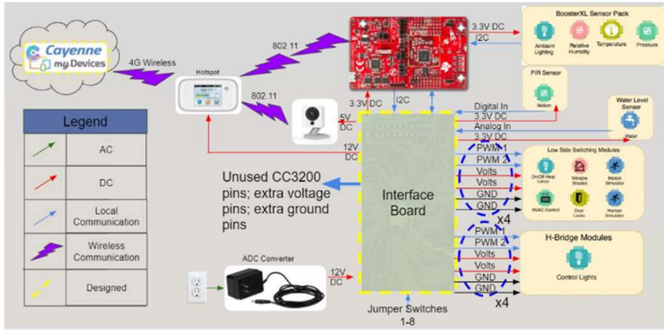

Figure 2. IoT House Instrumentation.

Figure 3. Complete Monitoring and Control Infrastructure.

All the CC3200 Launchpad embedded intelligence subsystems are linked to the internet via an 802.11/cellular hotspot. This approach allows the IoT house to be monitored and controlled without the need to be connected to the classroom/school wireless local area network. The hotspot provides communications to/from the Cayenne Dashboard. Students will be able to observe the operation of the system, collect data using different configurations, and create their own experiment scenarios using the capabilities of the Cayenne IoT Broker and associated dashboard shown in Figure 4.

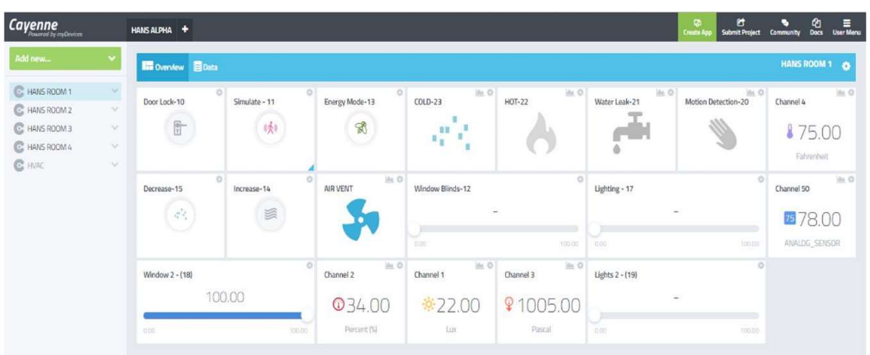

Figure 4. Cayenne Broker and Dashboard.

All of this capability is possible through the Interface Control Board (ICB) designed and built by the Capstone team. Shown in Figure 5, this board allows for a CC3200 Launchpad embedded intelligence board with associated daughter boards to be plugged into it.

Figure 5. IoT Interface Control Board.

The ICB provides power monitoring and distribution, actuator power, standardized wiring and interface connectors in a small form factor package. Through the use of the ICB, additional features and capabilities can be added to the IoT House in an easy and straightforward manner. Most new capabilities can be just plugged into one of the units located in each room of the house.

Obviously, this third generation building automation and IoT model house is the largest and most expensive of the three that were design by Capstone teams. The intent of this structure is to continue to reside at Texas A&M University and be managed by ESET. MMET and MXET students for remote use by primary and secondary school teachers as part of their math and science projects. As indicated, the students at lower levels might just observe the overall operation of the structure. At higher levels, student teams might create experiments that could be conducted using the hardware/software that currently exists; collecting and analyzing data obtained from the IoT system using the Cayenne dashboard. At the junior/senior level, students could develop their own dashboards based on their control algorithms and desired data to be collected. With the versatility of the version 3 model, all of these scenarios are possible.

The Version 3 model will be included in the Summer 2019 STEM Teachers Workshop hosted at Texas A&M University. Math and science teacher will be given the opportunity to develop curriculum models using this resource. During the workshop, the teachers will be able to test and refine their projects/teaching modules using students currently in junior high school. This will allow the teachers to leave the workshop with a validated project they can implement into their Fall/Spring semesters remotely from their classrooms.

In addition to a complete construction guide, documentation includes a comprehensive Build of Materials (Vendor, Part number, Description and Cost) to reproduce the entire IoT House. The cost to reproduce this structure, not including shipping or labor, is slightly less than \$3500 or approximately \$110 per square foot. Currently, the Version 3 IoT House can be monitored and controlled via the internet using the Cayenne Dashboard. Demonstrations can be conducted by a STEM teacher contacting the authors for the credentials and date/times of the desired demonstration.

Conclusions and Next Steps

There is an immediate need to engage more students in the areas of STEM while they still have an opportunity to pursue an educational path that will prepare them for higher education and a lifelong career in a STEM field of their choice. To this end, the faculty at Texas A&M

University have received project funding from the National Science Foundation as part of their Innovative Technology Experiences for Students and Teachers (ITEST) program. The entitled ”Connected STEM - Promoting STEM Education through Connected Devices and Building Automation” project seeks to use the areas of building automation, connected devices and additive manufacturing to excite teachers and students and promote STEM at the primary and secondary levels.

Over the past two years, the faculty have engaged with twenty-four teachers and hundreds of students. Part of this engagement includes a two-week workshop designed to give teachers engineering education and tools that will also them prepares them to incorporate engineering design and concepts in their curriculum. After the first workshop, it was noted while the teachers were receptive to the concepts presented, they needed more than just tools and education in order to be acceptable. Thus, the faculty, working with teams of undergraduate students, developed three different building automation and IoT platforms that could be used in the classroom as a focal point for primary and secondary engineering education curriculum modules. The third platform was a fourth scale building automation and IoT house that could be maintained at the University and used by the teachers both during the workshop and then remotely during the normal school year. This platform is complete and will be used at the Summer 2019 workshop. In addition, several other next steps are planned for this Version 3 platform.

The research team plans to leverage this resource in two ways in the near future. One of these to work with graduate students in the Department of Teaching, Learning and Culture within the College of Education at Texas A&M University. These efforts will focus on the design and implementation of teaching modules that can be offered to math and science teacher for use at the secondary education level. Currently, a doctorate-level student in education who has an engineering and computer science background is working with the IoT House design team to begin this development process. Using this interaction as a model, the ITEST research team hopes to support more collaborative efforts between the two colleges.

The second activity that is currently planned is to utilize the IoT House in the upcoming summer STEM teacher workshop. This focused effort of teaching teachers about engineering design, additive manufacturing, energy management, building automation and IoT technologies should produce a number of projects that will include the IoT House. Each of these modules will be tested and refined and shared with the participants. The goal will be to use the IoT House to support a number of student projects during the fall 2019 and spring 2020 semesters.

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