

Building Automation and IoT as a Platform for Introducing STEM Education in K-12

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Abstract

There is growing concern in the United States about the lack of interest and aptitude in science, math and, in particular, technology and engineering disciplines. Certainly one reason for this could be the lack of true engineering experiences available to students when they are in junior high and high school. This is in part due to the fact that while most teachers are well versed in math and science through their formal education, very few have experience and/or educational backgrounds in engineering and technology.

To promote STEM careers, a partnership among university engineering faculty, practicing engineers, and secondary schools is necessary; it is important to demonstrate to young potential STEM professionals the relevance of STEM activities. In addition to interacting with practicing professionals, authentic experiential learning activities for students in secondary education can promote STEM careers. Recently, the authors were awarded a National Science Foundation (NSF) grant as part of the Innovative Technology Experiences for Students and Teachers (ITEST) program to develop such partnerships and activities.

As part of this ITEST project, the fields of building automation, internet of things, and additive manufacturing was chosen as the focus area for all planned activities. This work-in-progress paper will present the ongoing work for this project, including the concept of using building automation to introduce teachers and students to STEM concepts, a novel summer workshop for secondary education teachers, the development of a simple building automation platform that can be deployed in secondary education classrooms, and the development of educational partnerships with industry to introduce and excite secondary education students about the STEM opportunities.

Introduction

There is growing concern in the US about the lack of interest and aptitude in science, technology, engineering and math (STEM) disciplines. While most teachers are well versed in math and science through their formal education, very few have experience and/or educational backgrounds in engineering and technology. Engineering is widely viewed as the application of math and science for the betterment of humanity. Presenting students with engineering and technology instruction will allow them to better understand the different aspects and interactions among the STEM disciplines. Given the prominence of engineering in both state [1] and the national Next Generation Science standards [2], this is a critical need. The work in this National Science Foundation (NSF) Innovative Technology Experiences for Students and Teachers (ITEST) project is designed to increase teachers' use of engineering design and students' understanding of engineering careers through authentic [3] product development experiences using connected devices. Two of the most exciting and transformational technologies today are connected devices [4] and additive manufacturing [5]. These two technologies have the potential to drastically alter business models and upend entire industries. As major companies adopt these technologies, the workforce of the future will need to be comfortable working with these connected devices, how new manufacturing processes work, and understanding the role these technologies can play in the modern enterprise.

To promote STEM careers, a partnership among university engineering faculty, practicing engineers, and the schools is necessary; it is important to demonstrate to young potential STEM professionals the relevance of STEM activities [6]. In addition to interacting with practicing professionals, authentic experiential learning activities can promote STEM careers. Experiential learning attempts to rectify what Kolb characterized as the “rejection” of the “real-world” by the educational establishment [7]. The key to experiential learning is the creation of knowledge “through the transformation of experience” [7]. In this project, this experience will be the development of connected devices aimed at building automation applications. This will allow students to experience, reflect, think, and act as part of a holistic educational experience [8]. This design experience will incorporate context, task, impact, and value authenticity [3] by incorporating the design of an actual device using industry tools to evaluate aspects of the school (or camp) environment. These activities will be supported by both engineering faculty and industry personnel to provide scaffolding for both the instructors and the students.

This project attempts to promote interest in STEM through the 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. The goal will be accomplished through five objectives.

- *Objective 1:* Increase teacher use of engineering design and product development process
- *Objective 2:* Increase student understanding of the engineering design process and engineering careers
- *Objective 3:* Stimulate student interest in math and science
- *Objective 4:* Increase high school student career interest and opportunities in building automation
- *Objective 5:* Promote parental understanding of engineering careers and technological development

This paper presents the ongoing work for this project, including the concept of using building automation to introduce teachers and students to STEM concepts, a novel summer workshop for secondary education teachers, the development of a simple building automation platform that can be deployed in secondary education classrooms, and the development of educational partnerships with the building automation industry to introduce and excite secondary education students about the STEM opportunities available in the field of building automation.

Background

The research team has previously participated in a number of STEM education projects focused on motivating young K-12 men and women to seriously consider engineering as a career path. Most of these projects have included building robotic systems controlled using embedded intelligence. In each project, students worked in teams where each person had a lead responsibility. These lead roles included mechanical subsystems, electronic subsystems, software subsystems and testing/optimization. Most of the projects began were developed by college students at the sophomore to senior level and offered as summer workshops through the College of Engineering, College of Education and other STEM organizations.

The first embedded systems-based workshop that was offered was the Krisys (pronounce “Crisis”) workshops. Students attending these workshops worked in teams of four to design, build and compete an autonomous three-wheeled robot. Some workshops were focused on

attracting female students while others were reserved for minority and under-represented students across Texas and the Nation.

The most recent workshops that are being offered uses the Digital Systems Teaching and Research (DSTR – pronounced “Disaster”) Robot. This four-wheeled, differential steering robot includes a Texas Instruments LaunchPad microcontroller, wireless networking and a phone app to allow the user to control the robot remotely. Both the Krisys and DSTR robots continue to be used and improved through lab and capstone projects.

The team also brings teacher enhancement experiences to the project. Faculty have participated in teacher and curriculum development workshops hosted by the College of Engineering, the College of Education, and local groups involved with preparing math and science teacher to integrate more technology and engineering into their high school courses.

Finally the research team has experience in all three of the primary areas associated with this project; Building Automation, Internet of Things (IoT) and additive manufacturing. Currently, the department has an industry-supported technical elective focused on energy management and building automation. Curriculum content and industry subject matter experts will be drawn from this course/laboratory as a starting point for the workshop being planned for STEM secondary school teacher in the summer 2017.

Finally, the department is a leader in the development of undergraduate course/lab material in the emerging technology area of Internet of Things. This includes both a technical elective course and capstone projects. Companies such as Texas Instruments, National Instruments, Keysight Technologies, and PTC have provided subject matter expertise, curriculum, and other funding and equipment resources to support the development of this important educational area. All of these materials and experiences will be leveraged to build a meaningful experiential learning opportunity for the 4th through 12th grade teachers attending the summer workshop.

Building Automation ITEST Project

Overview

Because of the department’s inherent interdisciplinary nature, ongoing faculty interest in Internet of Things (IoT)/ building automation/additive manufacturing, and interest in STEM education research, a faculty team proposed to NSF the idea of using IoT, building automation, and additive manufacturing to develop young (4th through 12th grade) students’ interest in pursuing education and careers in STEM related disciplines. These three technical areas were chosen as the platform due to their currency, availability of rewarding STEM careers, and ability to develop interest and excite students. As of fall 2016, the project was funded through the ITEST program and the team began working on the project.

The project is broken into three parts, identifying 4th through 12th grade teachers for participation in the project and educating them in the technical areas discussed above, supporting ongoing curriculum development and delivery of said curriculum in regional schools by the participants, and assessment of the results to measure whether the project is having an impact in promoting STEM-related fields to young students as a career path.

Building Automation, IoT and Additive Manufacturing as a Platform

As discussed, the ITEST team will use the technical areas of building automation, IoT and additive manufacturing as a platform to engage students and promote their interest in STEM careers. Specifically, the project will create a simple-to-use IoT platform where students can

deploy sensors (temperature, light, occupancy, humidity, etc) in their classroom. To this end, they will be given a set of basic sensor boards and they will need to decide how best to place these boards in their classroom to collect environmental information. As part of this deployment, they will study 3D printing and create appropriate enclosures for their sensors so they can be placed and powered efficiently.

Once the sensor system is deployed, the students will wirelessly collect environmental data over a period of time and evaluate the data using IoT data aggregation software. They will then make decisions on how to best optimize their classroom for automation and efficient energy usage. For example, they might collect data on whether the lights are left on when the room is not occupied. From this data, they may create a plan to turn off the lights either manually or automatically when the room is empty to save energy. As another example, they might collect temperature data and notice that room increases in temperature when the sun is up. From this they might conclude that their room needs solar screens and then test this hypothesis by applying film to the windows of the classroom and collecting additional data to see the impact.

Summer Workshops

An integral part of the ITEST project is to involve 4th through 12th grade educators in the process and have them create and deploy relevant curriculum in their classrooms in order to have direct impact on young students. To support this goal, the team will run summer workshops where 4th through 12th grade educators from regional schools will be identified and then trained in the relevant technologies. These workshops will last two weeks where the first week will be “teaching the teachers” and the second week will be devoted to assisting the teachers in developing appropriate curriculum that integrates the technologies discussed above into their classroom. As part of the second week, the teachers will have an opportunity to try out their curriculum on local 4th through 12th grade students.

Ongoing Support

At the conclusion of the workshop, the teachers will then bring their newly developed ideas back to their classroom for deployment. The ITEST team will continue to support the workshop participants as they install the technologies that they received in the workshop and begin to using it over the course of the year as a learning platform for their students. In addition, the ITEST team will help the workshop participants by hosting periodic “industry nights” where parents, teachers and students can meet industry practitioners, parents can see what technology their children have been using in the classroom, and parents, teachers and students can hear from successful individuals who currently have relevant STEM careers.

Assessment

Finally, ongoing assessment will be performed. The participating teachers will be assessed to ensure they can easily adopt and use relevant STEM technology in the classroom. Students will also be assessed before and after to measure the impact of using technology in the classroom and exposure to industry professionals on their desire to pursue STEM careers. Finally, overall success of the project will be assessed to see how extensively it is being adopted by teachers not directly involved in the ITEST project.

Current Efforts

Development of Summer Workshop

The most pressing need for this project is the selection of the first class of 4th through 12th grade educator participants and the development of the workshop that will be run this summer. To this end, the team has created an application process that allows teachers to apply to the program. The application has been specifically designed to cull educators who have a true interest in promoting STEM in the classroom and that have the ability to form a long-term relationship with the ITEST team, continuing their involvement in the project past the summer workshop and introducing the concepts and technology learned into their classroom as part of their formal curriculum. The ITEST team is also meeting regularly every two weeks as they select the technology platforms and develop instructional materials to be used in the first summer workshop. To date, the team has selected a specific 3D printer and the embedded IoT technology that will be used to introduce building automation concepts in the classroom. Educational materials are already being developed around these platforms. The team is also currently creating a web portal that will help in the dissemination of the materials being developed to a broader audience and will also be used as a support portal for the K-12 educator participants after they return to their respective schools. Finally, the team has finalized the logistics for the summer workshop including lodging, transportation and classrooms.

3D Printing

To provide students with an authentic design and development experience, they will create a physical enclosure for their devices using computer-aided design (CAD) tools and 3D printers. This component of the design experience will be augmented by an overview of the design process that allows students to understand how to generate concepts, select from among those concepts, and then advance a proposed design. The proposed design will be created in the open-source CAD program, such as FreeCAD. This will allow for schools to easily incorporate the project into their curriculum without having to secure software licenses.

As part of the ITEST project, each participating teacher will be given a FLASHFORGE Dreamer® Dual Extrusion 3D Printer and necessary filament to make several iterations of the enclosure concepts and final products. The inclusion of these physical artifacts not only allows students to be introduced to the exciting technology of additive manufacturing, but also to learn about geometry, physical constraints, and the connection between digital design and physical output.

Development Platform Selection

In parallel with teaching materials and laboratory projects being created in the area of 3D printing, the research team will be developing a Texas Instrument LaunchPad- based IoT device to be used in the workshops which will become one of the major building blocks for STEM educational modules. The IoT Building Monitoring Device (IBMD) will be composed of a CC3200 LaunchPad, a plug-in BoostXL-Sensor pack, and a battery. These three items will be housed in an enclosure that is designed and fabricated using the 3D printer provided as an in-class resource to the teachers attending the summer workshop. The LaunchPad will be programmed using the new Arduino-like Energia development environment. Programs will be provided for the various teaching modules that are included in the workshop and teachers will learn to edit and modify existing code to add various features and capabilities to the basic programs. The goal will be to have the teachers develop a building monitoring unit which senses a number of

environmental parameters and transfers these data to the cloud for post-processing and analysis. The current plan is for each teacher who attends the workshop to receive five of the building environmental sensors to support here course modules.

Industry Support

One of the key elements of this project is to ensure that STEM partnerships are created with industry and the companies are engaged with both 4th through 12th grade teachers and students in support of curriculum development, delivery of coursework, and direct student interactions. For this reason, an advisory committee has been created to engage industry and solicit their ideas and feedback. The committee met for the first time in the Fall of 2016 and will continue to meet at least twice per year for the duration of the project. Through these ongoing interactions, several companies are now actively involved and have committed personnel and resources to ensure success of the project and to help create a model for future STEM partnerships. Some of these companies include:

- Schneider Electric – Schneider is a leading company in the energy and building automation sectors and the authors have a long-term partnership with them in the area of energy management and building automation education. For this project, Schneider brings to the table a current perspective on the state of the building automation industry including knowledge of careers. In addition, Schneider Electric operates Schneider University, an open access web-based educational resource to help customers and the public understand the concepts of energy management and building automation. The ITEST project leverages this unique resource as an educational tool allowing 4th through 12th grade teachers to rapidly advance their knowledge as well as receive professional development credit. Specifically, Schneider University now supports a professional development track designed specifically for this project that includes five online courses and that is accessible by the 4th through 12th grade educators involved in this project to facilitate learning about building automation and the careers available in this area.
- Texas Instruments - Another major industry collaborator is Texas Instruments. The research team chose the TI LaunchPad technology based on a number of reasons. First the LaunchPad product line offered by Texas Instruments is an economical and expandable development platform that has several alternatives as to on-board intelligence, sensors and wired and wireless communications options. TI has agreed to support the ITEST project with their CC3200 LaunchPad and BoostXL-Sensor Pack which is a two-board solution containing ten different sensor technologies, a robust microcontroller and WiFi communications. This small form factor solution will act as the edge device for the IoT system collecting data from its various sensors and publishing these data to the cloud via wireless internet connectivity. These two-board modules will be housed in an enclosure that teachers will design the 3D Print as part of the workshop. The enclosed modules can then be distributed around a class room or throughout the school. The second reason the research team selected the TI LaunchPad was because it could be programmed using a user-friendly, Arduino-like program environment. Known as Energia, this development environment provides an ecosystem that fully supports novice and inexperienced software developers. Code segments are available online and are easily integrated together to form a complete IoT data acquisition edge device.
- PTC - PTC is yet another industry collaborator and has agreed to provide its ThingWorx resources to the project. ThingWorx instances that can execute locally will be made available to the teachers attending the workshop so that data collected by the TI LaunchPad

edge device can uplink its data to a cloud environment without having to pass through the school's firewalls. This should make standing up the system at various junior/high schools a much more uniform process. Once data have been published to the ThingWorx cloud, users will be able to log in, manipulate and display the data graphically for all the sensor devices available. The LauchPad/Energia/ThingWorx IoT system will allow junior and high school students to gain a much fuller appreciation of IoT technology.

- **Stratasys** - A member of Stratasys' staff is part of the project advisory group; Stratasys is one of the additive manufacturing industry's leading companies. This individual has the unique perspective of having been a teacher prior to transitioning to industry. This will allow him to not only comment on how best to incorporate additive manufacturing into the classroom from a technological perspective, but also better understand any potential pitfalls and problems from the educator's perspective.

In addition to supporting this project through participation on an advisory board and providing educational, hardware, and software resources, the industries involved in the ITEST project will participate in "industry nights" held at the participating schools. The concept of "industry nights" allow teachers, students, and their parents to interact with industry professionals who currently have successful STEM careers. Often students and their parents are hesitant about the possibility of a technical career because of anxiety in having to apply mathematics and science. The goal of these interactions are to allow students and their parents to meet "real" individuals who have chosen STEM career paths and hear first-hand about the exciting careers and rewards that can be found in these areas.

Future Work

Summer Workshops

The research plan calls for the offering of a teacher workshop each summer. The workshops will be attended by junior and high school STEM in-service teachers from the Houston ISD and other areas as needed. Preference will be given to schools that have the ability to send two or three teachers representing Math, Science, and engineering/technology who will work together to build new curriculum.

During the first week of the workshop, the research team will be teaching the teachers. These teachers will also work with the research team to develop new secondary school educational curricula for both 3D Printing and IoT technology for building monitoring and energy management activities. During the second week of the workshop, the teachers will dry-run their new curricula on junior high and high school students who will be invited to attend from the local community.

The overall intent or game plan is provide the teachers with the tools and knowledge of these new technologies and then support them as they develop new cross discipline teaching curriculum. These new curricula will be tested on real students and then made available to a larger number of school districts and teachers. Each summer, a new group of 10 teachers will be selected to attend a workshop where they will continue to expand the curriculum with new teaching modules, challenges and learning objectives.

Post Workshop Support

Once the first workshop is concluded this summer, the project team will move into a support role to ensure that the teachers involved continue to develop curriculum ideas and begin

deploying the technology that they received into their classrooms. It is understood that while the educators that attend the summer workshop should feel comfortable with 3D printing and building automation technology at its conclusion, this is only a single exposure and that they may lose some of their confidence in working with the concepts and technology they learned once they return to their school. To this end, continued support will be provided in two forms. These include:

- **Web-based support:** The ITEST team has created a web portal where support documentation can be posted. In addition to the summer workshop training materials; quick-start guides, reference material and troubleshooting guides are currently being developed and will be posted on the website to support educators as they return to their schools and begin deploying the tools they received at the end of the workshop. Also, the Schneider University online professional development track will continue to be available to the educators so that they can refresh their understanding of building automation as they introduce this material in their classrooms.
- **Phone and in-person support:** In addition to the web support, the ITEST team will be available by phone and, if necessary, through on-site visits to make sure that the workshop participants are able to install and use the building automation and 3D printing materials in their classrooms. It should be noted that the ITEST team has had previous success in leveraging the abilities of undergraduate students to support external “customers” and it is anticipated that this methodology can be used here.

Assessment

To assess the role of authentic design experiences on interest in and understanding of STEM careers, a two pronged approach will be used. The first is a research approach using both quantitative and qualitative data. The second is an external evaluation that will assess if the proposed project goals were met by the outlined activities.

In the case of the research, three populations will be evaluated: parents, teachers, and students. The teachers will be evaluated using a pre- and post- evaluation method to determine their understanding of the engineering design process, going from a digital design to a physical component, connected devices, and the skills and job responsibilities associated with STEM careers. The pre-assessment will be done prior to the teachers’ summer continuing education program and the post-assessment will be done after the completion of the program. Students will be assessed using two alternative control groups. The first will be those that of a different population near the end of the same course without the intervention of the ITEST program; the second will be a pre-intervention assessment of the study population. This study population will also be assessed after the implementation of the authentic experiential exercises into their class. Finally, parents will be asked to self-assess the role that the activities had on their understanding of STEM careers and their perception of the effect of the activities on their children.

The external evaluator will assess the effectiveness of the summer professional development program for teachers by looking at their overall engagement and satisfaction with the program. They will also ensure that the curriculum has been implemented and assess the number of students that have been affected. The external evaluator will work with the students to assess their perception of the authentic experiential learning exercises. The external evaluation process will serve a “check” on the accomplishment of the goals associated with the overall project.

Conclusions

The ITEST project is designed to increase the interest in STEM-related education and careers at the 4th through 12th grade level. The project team is specifically using the areas of building automation, IoT, and additive manufacturing as the environment to achieve this goal due to its accessibility and perceived ability to excite students and help them visualize their own ability to be successful in these career paths. To date, the team has accomplished several tasks necessary for the success of this project that include:

- creating an industry advisory team from appropriate technology sectors to assist in planning. The team has already met once and will meet again in the Spring of 2017,
- starting the process of finding and selecting suitable 4th through 12th grade education professionals to take part in the first class of participants,
- organizing the logistics of the summer workshop that will bring the 4th through 12th grade education participants up to speed in the relevant technology areas,
- and developing the training materials necessary for the delivery of this summer's teacher workshop.

While the project is ongoing, it is anticipated that preliminary results will be presented at the ASEE conference this summer including techniques used to select suitable candidates for participation in such a project, the response of 4th through 12th grade educators to the online STEM training material in the area of building automation, and lessons-learned in the planning and creation of the summer workshop. Finally, it is anticipated that the team will publish several papers on the outcomes of the ITEST project at its conclusion.

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