# Embedded System Education Curriculum using TI SimpleLink Microcontrollers in Engineering Technology

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## Abstract

In Engineering Technology programs, it is typical to find that microcontroller and embedded system education is selected as one of the key areas. This is relevant to the increased demands in a shorter and faster paced research and development in electronics systems design. In order to meet the functional requirements for the electronics systems, one of the typical choices is to use a general-purpose microcontroller, sensors, and communication modules. In embedded system education, the topics related to these components can be covered. The Engineering Technology program at Texas A&M University has been educating students through embedded C programming, microcontroller architecture, and embedded system software courses. The program also offers a technical elective on an embedded real time software development course and a graduate level intelligent embedded system design course. Various models of Texas Instruments (TI) microcontrollers have been previously used in the courses in the embedded system integration track. However, from the Fall of 2019, an MSP432 microcontroller (MCU) was selected and has been used as a common platform throughout the majority of the embedded system courses. An MSP432 MCU has an ARM Cortex M4F core and MSP430 compatible peripherals. Students learn about the register level C programming, microcontroller architecture, and ARM assembly language programming skills and knowledge. They also learn about high level of programming using TI driver library and TI real-time operating system (RTOS) in this embedded system integration track. An MSP432 MCU is one of the SimpleLink family platforms. The SimpleLink family platforms make the development cycle faster and easier to meet the various requirements. The SimpleLink family platforms are currently active microcontrollers and microprocessors. In the Engineering Technology at Texas A&M University, the courses in the embedded system integration track have adopted an MSP432 MCU as a common platform. Students can choose to use other SimpleLink platforms for their capstone projects because their knowledge is still relevant and there is a high chance of reusing their code within the SimpleLink family platforms. This paper presents the details of the embedded system track and this transitional progress and students' learning throughout this embedded system course curriculum for Fall of 2019 and Spring 2020.


## I. Introduction

Embedded System education is an important area in Engineering Technology programs. It has gained more popularity and became more relevant as we see more educational, hobby-level, and industrial microcontroller and microprocessor applications. The importance of this area is also related to the increased demands in a shorter and faster paced research and development in electronics systems design. The prototypes can be easily found to be a form of embedded system applications. One of the examples is an electronics system that uses a general-purpose microcontroller with sensors and communication modules, which can be adapted and applied to various other applications.

The Electronic Systems Engineering Technology Program at Texas A&M University was established in the early 1970's and was first accredited by ABET in 1975. In 2012, the program had a name change from Electronics Engineering Technology to the current *Electronic Systems*

*Engineering Technology (ESET)*. The ESET program is part of the Department of *Engineering Technology and Industrial Distribution (ETID)* at Texas A&M University as of today. An embedded system field is one of the key areas in this program. In this Embedded Systems Integration area, students learn about Digital Electronics, Embedded C programming, Microcontroller Architecture, and Embedded System courses. There are more courses to take for students such as an embedded real-time software development course as a technical elective and embedded intelligent system design course as a graduate level course.

Students have learned about microcontrollers and microprocessors from Texas Instruments (TI). Some of the prior MCU models are MSP430, MSP432, Hercules, CC3100, and TIVA. From Fall of 2019, an MSP432 MCU was selected and it has been used in undergraduate level embedded system courses. The educators in the ESET program are pursuing to keep up with the industry trend. As of today, Texas Instruments provides three groups in the categories of 16-bit and 32-bit MCUs. They are ARM-based SimpleLink microcontrollers, MS430 microcontrollers, and C2000 microcontrollers. An MSP432P401R MCU has an ARM Cortex M4F core and MSP430 compatible peripherals. It is one of the ARM-based SimpleLink microprocessors.

SimpleLink microcontroller platforms can provide developers new perspectives on IoT (Internet of Things) product development. For instance, the developers may need to find a new microcontroller in order to meet new design specification and requirements. In the SimpleLink solution, the developers can adopt a new microcontroller and reuse their existing code used in their other microcontrollers. This offers a great flexibility in the IoT device development. As of today, the number of the microcontroller models in the SimpleLink family is a little more than 90. The supported profile of the microcontrollers will be most likely increased. The SimpleLink family was grouped as wired, WiFi, Buletooth, Sub-1GHz, Zigbee, Thread, and multi-standard microcontrollers. The key concept is to provide very high code portability within the SimpleLink platforms. For instance, the code that was written for an MSP432 MCU can be reusable in a different SimpleLink family MCU with WiFi and Bluetooth modules. Hence, the choice of an MSP432 MCU in the ESET program does not limit to only one microcontroller. In fact, this choice of this specific SimpleLink MCU makes it possible to expand to a bigger scope of the microcontroller groups of SimpleLink platforms. In fact, it is observed that students choose the MSP432 MCU or different SimpleLink MCUs in their senior/capstone projects in our program.

Throughout the academic year of Fall 2019 and Spring 2020, an MSP432 MCU has been used and taught in three different courses throughout the embedded system integration track in the ESET program from sophomore to junior/senior undergraduate students [1]. In this paper, the details of the courses in the embedded system integration track and transitional progress and students' learning progress throughout the embedded system course curriculum

## II. Embedded System Integration Track

The ETID department offers an Embedded System Integration minor. Students learn about embedded system hardware and software development and how these systems are used in products and electronics. This minor requires five courses of 18 hours and is open to engineering students and non-engineering students in other departments. The five courses are *Digital Electronics, Embedded Systems Development in C, Product Development, Microcontroller*

*Architecture*, and *Embedded System Software*. These courses are also required courses for Bachelor of Science (B.S.) degree of the ESET program.

Students at Texas A&M University enter the program via several mechanisms, and the majority of them enter the program through an Entry-To-A-Major (ETAM) process. This process is for students who have successfully completed their Freshmen Engineering program, and they apply for a program of their choice. The ETID department offers several Bachelor of Science degree programs in the areas of *Electronic Systems Engineering Technology (ESET), Manufacturing and Mechanical Engineering Technology (MMET), Multidisciplinary Engineering Technology (MXET),* and *Industrial Distribution (ID)*.

Students who joined the ESET program may take a Digital Electronics course. In this course, students learn about the fundamentals of the digital logic circuits and applications. Moreover, students may take Embedded Systems Development in C course. In this course, students learn about the C programming language and the programming using a microcontroller. Students who take this course are getting familiar with an MSP432 development board.

After successful competition of these two courses, students can take a microcontroller architecture course. In this course, students can learn in-depth knowledge about how microcontrollers function, how instruction sets are configured, and how they are programmed. In this course, students learn about an ARM Cortex M4F architecture. Since an MSP432 MCU has an ARM Cortex M4F core, this MSP432 Launchpad is a suitable choice for this course. Students learn about the low-level assembly languages and the instruction set architecture through this course.

Microcontroller architecture course is a prerequisite for the next embedded system software course. In this embedded system software course, students will learn about technical aspects of embedded systems and the applications with the emphasis on embedded real-time systems, programming techniques and development methodologies. In this course, students learn about various peripheral modules and their applications. Students extend their knowledge about the MSP432P401R MCU, and use it to build a customized education board and/or create their own embedded system applications [2].

The ESET program has rigorous two semester Capstone courses. Successful completion of this embedded systems course is a prerequisite to the ESET 419 Capstone course. Moreover, successful completion of this embedded systems course is also a prerequisite to take an embedded real time software development course. This is a technical elective course. In this course, students can learn about the operation and use of real time kernels as well as embedded RTOS applications. Students use an MSP432P401R board and educational booster pack in this course [3].

For the advanced embedded system education, the ESET program offers a graduate level course. The course title is *Embedded Intelligent System Design*. It was offered in Fall of 2019, and it is planned to be offered again. Students can learn about Linux based embedded systems and artificial intelligence system applications in this course.

For effective teaching, it is important to provide good learning environments. And, it is particularly important for embedded system education because many students can obtain the knowledge through hand-on learning experience. The pictures of the lecture room and laboratory room are shown in Figure 1. Lectures may take place in various locations based on the number of students and availability of the classrooms. However, this is the picture for the embedded system software classroom in Fall 2019. This classroom is designed to support active learning. As it can be seen, it is not a traditional classroom. It is well designed to practice active learning activities for students' learning. For the laboratory room, it was remodeled to support various programming and design activities in a collaborative environment in a large open space. Each table has an equipment set including oscilloscope, power supply, benchtop multimeter, and laboratory PC. The room has a closet that can store several lab kits to serve different classes. The large open space in this laboratory enables students to collaborate and communicate well with each other as well as with the laboratory instructors.


**Figure 1. Lecture room and Laboratory room for embedded system education**

## III. Course Curriculum using MSP432 MCUs

### A. Digital Electronics Course

This ESET 219 digital electronics course is designed to teach students about digital electronics and their applications. The focus is primarily on the design of combinational and sequential logic

circuits. These circuits are implemented in laboratory exercises through the schematic capture editor using an FPGA platform.

The beginning portion of this course is to teach students about binary, decimal, and hexadecimal numbering systems as well as binary codes and digital systems handling numbers and codes. Next, students start to learn about digital logic circuits. It involves logic gates, simplification methods of Boolean equations, and combinational logic design for custom design applications.

After learning about the basic logic circuits and devices, students learn more about the combinational logic circuits. They include adders, multiplexers, de-multiplexers, encoders, decoders, and comparators. Students are going to understand that these logic circuits and devices are not arbitrary but they are frequently found in many electronics. For example, multiplexers are used in a microcontroller to switch pin outputs, clocks, and other signals.

The final part of the digital electronics course is learning about flip-flops and the devices that are constructed from flip-flops such as counters, frequency dividers, and pulse width modulation circuits. Sequential logic design is taught to show students how a state machine can be created. This knowledge is also essential in constructing their final project of a line following robot.

After completing the course, students gain an understanding of binary number systems, digital circuit schematics, combinational and sequential logic systems. These skills are necessary to understand the hardware of an MSP432 MCU. The knowledge they learned in this course can be applied to the following multiple courses.

**B. Embedded Systems Development in C (ESET 219)**

The ESET 269 embedded systems development in C course can be taken with the ESET 219 digital electronics course. This ESET 269 course is focused on learning about C programming language and how they can be applied to an embedded system. An MSP432 MCU is selected as the microcontroller platform for the course. An MSP432 Launchpad board is used in laboratory experiments, which allows students to easily prototype with hardware while programming.

This course assumes that students do not have prior C programming experience. This course shows functions and programming practices in C that are commonly used in microcontroller programming. The topics that are not relevant to the microcontrollers are avoided. The programming environment is Keil MDK [4]. This Keil MDK supports multiple microcontrollers with ARM cores inside. This tool allows students to use it for the development of an embedded system with various other MCUs

This course begins with learning data types, syntax, and displaying output and reading input via a console terminal. A laboratory template code is given to students to redirect *printf* and *scanf* functions. This allows students to use the MSP432 Launchpad in learning C, as they figure out the basic read and write functions via a console terminal. As students become comfortable with coding, they learn more about loops, if-else statements, switch statements, and arrays. By the middle of the semester, students are getting familiar with pointers, creating custom functions, and organizing a program into multiple header and source code files.

During the rest of the course, students will study about the programming in C and the hardware peripherals of an MSP432 MCU. The intent is to introduce several common peripherals that will be used in other courses. These peripherals include general-purpose input and output (GPIO), timers, Universal asynchronous receiver-transmitter (UART), and analog to digital converter (ADC). As a final project, students create an interactive menu via a console terminal, which can control the Launchpad and read data from the Launchpad. This final project involves controlling an RGB LED, reading switches, and reading data from a temperature sensor. An example of the hardware setup and the console terminal display is shown in Figure 2.

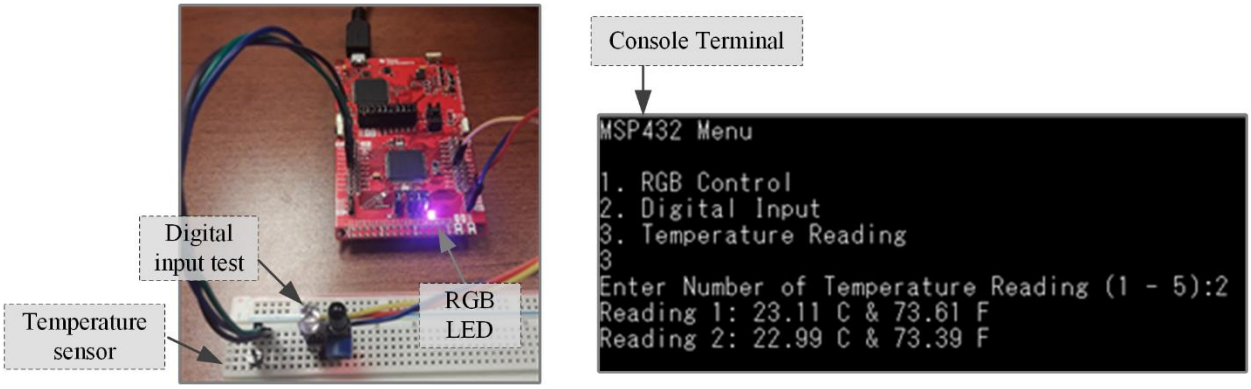


**Figure 2. Final Project Hardware Setup and Example Console Window**

Upon completion of this course, students are getting familiar with programming in C using an MSP432 MCU. This course serves as a bridge to the next courses including ESET 349 microcontroller architecture and ESET 369 Embedded System Software.

### C. Microcontroller Architecture (ESET 349)

In the ESET 349 microcontroller architecture course, students will learn about microcontroller architectures, instruction sets, and how to program. This course covers hardware and software concepts and principles of microcontrollers. A MSP432P401R Launchpad has been used as the primary microcontroller unit. In this course, students learn about assembly language, and they increase their understanding of the platform. An ARM Cortex-M microcontroller architecture is studied and the MSP432 MCU is explained in detail. The major elements of the microcontroller are studied including ALU (arithmetic logic unit), registers, and memory spaces including ROM and RAM as well as special registers in the memory to access GPIOs. A brief discussion on MIPS (Microprocessor without Interlocked Pipelined Stages) instructions is given at the beginning of this course. Next, students study about the ARM Cortex-M4F microcontroller.

From Fall 2019, this course was revised and has been concentrating on the microcontroller architecture and assembly language programming using an MSP432 MCU. One of the main emphasis is to use debug tools and IDE (Integrated development environment) properly to understand instructions, data exchanges between registers and memory spaces, memory address organization, and so forth. Students are required to record the debug results and create appropriate memory maps. This enables students to grasp a solid understanding of the microcontroller architecture and the foundation of assembly language programming. This process can give students valuable insights, and they can visualize how the microcontroller uses

the associated memory. Students can discover the strength of the assembly language programming over high level programming languages in certain cases. Students can write programs that move data within memory and they can implement sorting algorithms. Moreover, students learn to control GPIOs to interface with external circuit components on a prototyping breadboard using assembly language programming. Students will work in pairs to carry out their laboratories. Typically, there are nine laboratory assignments and one final project. Students choose their own term projects. Laboratory instructors help students in designing and implementing their projects. It can be found that some projects are complicated and nicely executed. Their projects may involve many components such as motors and distance sensors, and motion detectors.

### D. Embedded System Software (ESET 369)

After taking the ESET 349 microcontroller architecture course, students can take the ESET 369 embedded system software course. In this course, students learn about technical aspects of embedded computer software systems, with emphasis on embedded real-time systems, programming techniques and development methodologies. Students learn about the more in-depth study of the embedded systems in both hardware and software, microcontroller applications, and real-time operating system concept. To assist the students' learning process, a custom education board, BH EDU board was developed [5]. Students can access this board and the associated kit during their laboratory sessions. It is shown in Figure 3. Students learn various aspects of embedded systems and programming techniques using this BH EDU education board.

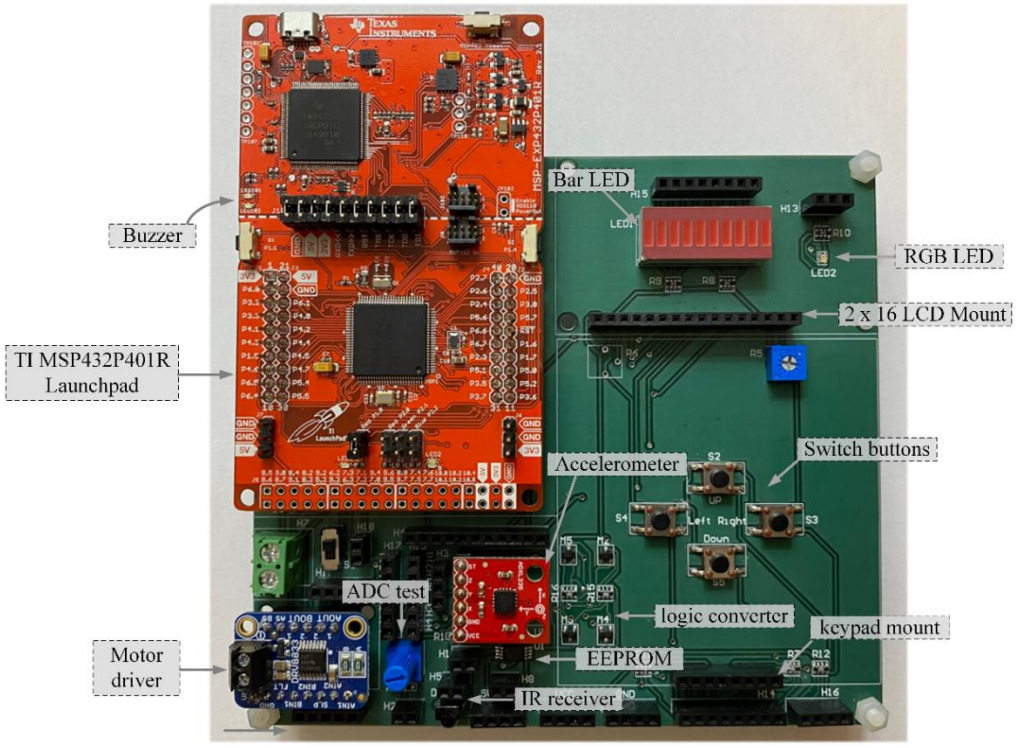


**Figure 3. Picture of the BH EDU Board**

At the end of the Fall 2019 semester, students were given a term project. Students have chosen to enter a robot challenge or design challenge. For the robot challenge, students needed to build a robot to perform the given manual and autonomous tasks. Most of students have chosen to build a robot using the BH EDU board. This is partially because the instructor provides relevant examples and instructions for the BH EDU robot case in class. There were 14 teams in this robot challenge category. Figure 4 shows one of the robots. It was created by one of the student teams. It is a Bluetooth controlled robot with a gripper [6]. The gripper is essential to meet the robot challenge requirement. For the design challenge, students propose their idea and build it. There were 20 teams in this design challenge category. Students have shown the complex and creative projects, and the instructor evaluated their project. In addition, peer students participated in the evaluation and the best project was determined by the peers.

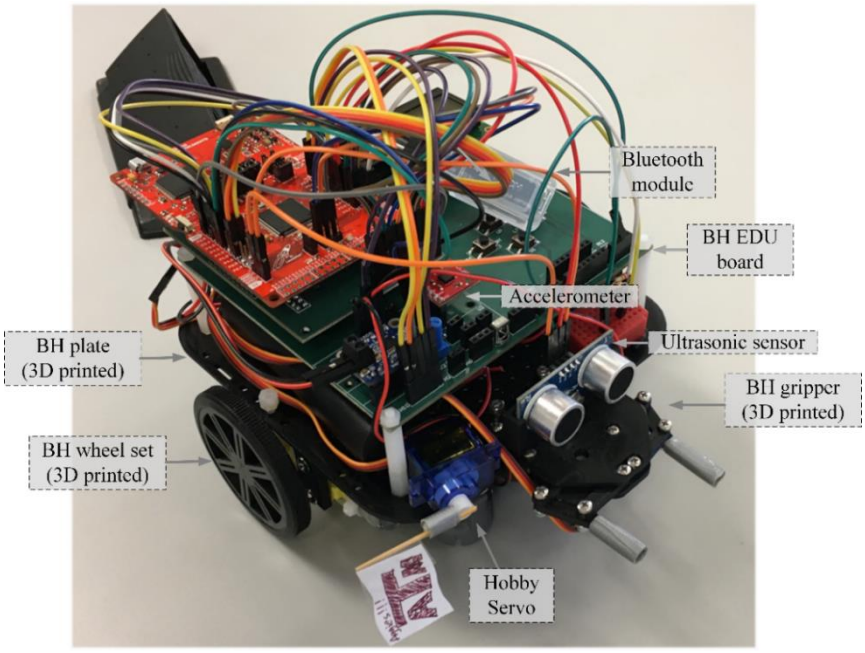


**Figure 4. Robot kit created by a student team using BH EDU board**

Embedded system course instructor compiled the lecture materials, and published textbooks to assist in learning embedded systems using an MSP432 MCU. The textbooks are consisted of two volumes. The first volume was published in January 2020, and the second volume was published in April 2020 [7],[8]. They have been adopted in the ESET 369 embedded system software course in Spring 2020. For the students who would like to learn more about the real-time operating system (RTOS) after taking this ESET 369, they can choose to take an ESET 469 embedded real time software development course to advance their knowledge in the embedded real time operating systems.

### E. Embedded Real Time Software Development (ESET 469)

In the ESET 469 embedded real time software development course, students learn about the real time kernels for the embedded system development. Students learn about task operation, inter-task communications, synchronization, dynamic memory, multitask system design and defensive

programming techniques as well as embedded RTOS applications. This course is a technical elective course, and it is typically offered once per year. Students will learn and practice industry level embedded system programming and coding. The instructor has already adopted an MSP432 MCU prior to Fall 2019. In Spring 2019, this course was offered. Educational BoosterPack boards were used with the MSP432P401R Launchpad board. Students have learn about available resources from TI and have a chance to develop their own firmware programs using TI RTOS [9],[10].

## IV. Course Statistics and Evaluations

The embedded system integration track in Engineering Technology Department have been providing effective and hands-on education to a good number of students. Figure 5 shows the number of enrolled students who have taken the courses in this embedded system track integration track from Fall 2018 to Spring 2020. There has been a steady and fast growth of this ETID department itself. This growth has been reflected to this graph. To compare the data for the two Fall semesters of 2018 and 2019, the numbers of students in Fall 2019 have been almost two times bigger than the ones in all three listed courses.

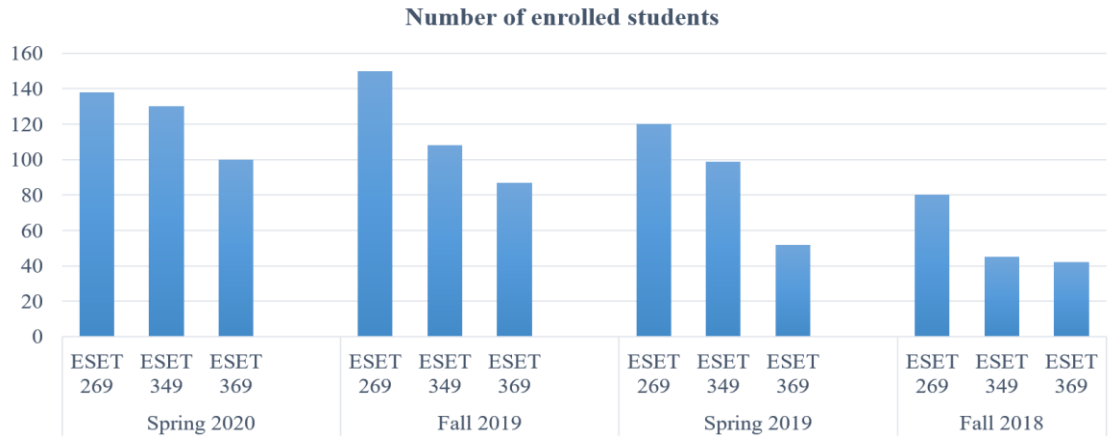


**Figure 5. Enrolled students who have taken embedded system integration track courses from Fall 2018 to Spring 2020.**

The total numbers of the listed courses are not small. However, they are divided by the multiple laboratory sections. In each laboratory section, there are 16 to 20 students or less. The numbers of sections from Fall 2018 to Spring 2020 are shown in Figure 6. As the enrolled students have been increased, the numbers of lab sections also have been increased accordingly.

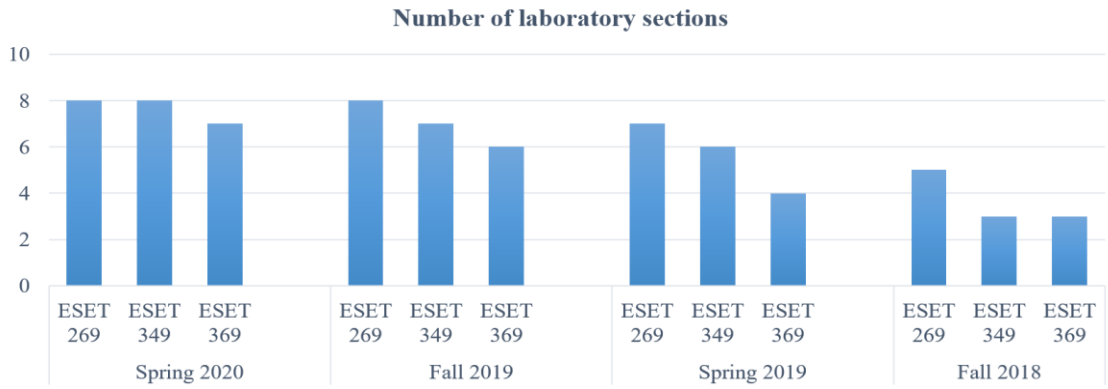


**Figure 6. Numbers of laboratory in embedded system integration track courses from Fall 2018 to Spring 2020**

In order to examine the impact to the students for the semesters where the MSP432 MCU has used, the data analysis is carried out and the results are shown in Table 1. In Fall 2019, the MSP432 MCU has been used in all three courses of ESET 269, ESET 349, and ESET 369. For ESET 469, it was offered in Spring 2019 but it was not offered in Fall 2019. So, Spring 2019 data was added instead. The total number of students in four courses who have used and learned about the MSP432 MCU were 349. This is not a small number of students. Many of these students have been impacted by the embedded system integration education and they have learned about the MSP432 MCU. The overall average of the students' evaluation in these courses is 3.93 out of 5.0 scale. It was calculated by the simple average across all the courses. From the students' feedback and the statistics, it shows that the MSP432 has been well accepted by students in this embedded system integration track. In Spring 2020, this MSP432 platform has been also used in the courses of the embedded system integration track. At the end of the last semester of Fall 2019, instructors had a curriculum meeting. Embedded system track instructors are aware of the impact to our students in choosing a SimpleLink MCU. Regarding the adoption of an MSP432 MCU, instructors have been closely monitoring the students' feedback and their learning process. In addition, instructors plan to continue to provide effective and hands-on learning experiences to students in this embedded system integration track.

| **Fall 2019** for ESET 269, ESET 349, ESET 369 | Total number of enrolled students | Number of responses | *Mean student evaluation | *Average numerical grade earned by students |
|---|---|---|---|---|
| **Spring 2019** for ESET 469 | **349** | 110 | *3.93 | *3.19 |

**Table 1. Embedded system track data analysis for the semester where MSP432 was used.**
**(***Simple average across all the courses**)**

## V. Discussion & Concluding remarks

Embedded system education is gaining more interest and more emphasis because the internet of things (IoTs) become more popular and they have been widely accepted in our everyday lives. In the embedded system integration track in the ESET has been pursuing to deliver an effective and hands-on education to the students. Due to the trend changes by the Texas Instruments, all of the

embedded system track courses have decided to use an MSP432 MCU. Each course studies about different perspectives and different levels of the MSP432 MCU. In embedded system track courses, it has been organized to deliver effective education and consistent education over the multiple courses. After taking the courses in the embedded system integration track, students take Capstone project courses. Students can choose their own microprocessor/microcontroller model according to the project requirements. They may choose one of the SimpleLink MCUs, and they can reuse the code of what they have learned previously. In this paper, an embedded system track that uses a common MSP432 MCU was presented and the assessment was shown and discussed. The positive feedback was demonstrated through the students' feedback and evaluation. The authors plan to monitor a longer-term effect regarding this education model. Since the product life cycle and development cycle of the microcontroller/microcontroller is not typically very long, there could be a possibility in adopting different MCUs in these courses in future. However, it has been very interesting to see this particular period time because all courses use a common MSP432 MCU and they can meet their education objectives. Authors plan to keep monitoring the educational impact in this direction, and plans to keep up with the industry trends.

## Acknowledgements

Thanks to Franklin Cooper of Texas Instruments for the MSP432 Launchpad support.

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