Establishing Baseline Data on Student Success in Embedded Systems Education

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***Abstract*— This Work-In-Progress paper reports on research which aims to establish a baseline assessment on students studying embedded systems to develop a series of educational hardware modules capable of inspiring student engagement and facilitating applied engineering education. The goal of the proposed modules is to significantly increase embedded systems competency and produce high-quality engineers capable of developing complex systems upon entering the work force. Students struggle to learn embedded systems, connect embedded topics between courses, and apply those topics to real-world applications, thus facilitating a need for Modular Embedded Tools (METs) integrated within an electrical and computer engineering curriculum. Current projects within the curriculum do not sufficiently engage students, educate on embedded topics, nor inspire curiosity for independent learning. Courses covering embedded systems, including Introduction to Engineering, Digital Systems: Logic Design, Fundamentals of Analog Circuits, Digital Systems: Hardware Programming, Embedded Systems: Microcontrollers, Embedded Systems: System On A Chip, Junior Design, and Senior Design have been targeted for study. An understanding of the current level of student engagement with present-day curriculum projects must be established to aid in the development of the METs system. This paper presents data collected from AY2022 detailing the current level of student competency, motivation and interest, level of independent ability to complete project assignments, the connection of embedded systems to other disciplines, and student readiness to solve real-world problems. The data was collected through a survey and semi-structured interview conducted with current and former students in embedded systems. The findings support the need for new educational tools capable of enhancing the student experience in embedded systems to increase engagement, inspire curiosity, and ultimately prepare students in a modern, more efficient way. Resulting from these findings, data presented has informed the next step of researching a preliminary design of such tools.**

Keywords—embedded systems, modular embedded tool system, modular education, curriculum

I. Introduction

Twenty years ago, top executives studying the market predicted embedded systems would grow exponentially and have significant importance during the decade [1]. Those predictions were absolutely correct: studies conducted during 2020 revealed a US market cap at $86.5 billion [2] and globally at $207.3 billion, with significant growth expected within the next five years [3]. As defined by L. De Micco, an embedded system refers to electronic equipment with a computing core which is designed to meet a specific function [4]. Being able to design an embedded system which is optimized for efficient energy consumption, cost, reliability, size, and execution is a challenging but necessary skill for electrical and computer engineers. As such, embedded systems are a pivotal topic within an electrical and computer engineering curriculum. Very few products, both commercially available and used professionally in industry, are built without embedded systems being involved in the creation or within the product itself. Unfortunately, global education of embedded systems has not managed to keep up with the pace of growth in the field, resulting in many challenges teaching embedded systems. These problems include translating fundamental theory to practical applications [5], connecting embedded systems to other disciplines, encouraging engagement, development, and reuse of code [6], as well as general student motivation, interest, and competency in the subject. These challenges have resulted in a lack of highly skilled engineers capable of developing embedded devices throughout all industries [7].

Our team, comprised of educators in engineering as well as practicing engineers, seeks to develop a Modular Embedded Tools (METs) system as the solution to the challenges within embedded systems education. The METs system will address the challenges encountered when teaching embedded systems such as student motivation and interest, connecting knowledge between classes, independently developing code, and applying technical knowledge to real world situations. To analyze the ability for a METs system to facilitate successful embedded systems education, a series of surveys and interviews were conducted from students in all selected courses who opted into the study. The objective was to gauge their knowledge in embedded systems, level of motivation and interest, connecting knowledge, and ability to translate knowledge to real-world systems. This data captures the current level of student success in embedded systems education and establishes a baseline to measure the effectiveness of implementing METs within the curriculum.

II. Methodology

A. Curriculum Courses

To improve and develop new techniques to enhance embedded systems education, an understanding of the courses within the curriculum, and their connection to the topic, must be established. Although the following courses are specific to the University of New Haven, each topic will appear within the curriculum of any program accredited by ABET. The Electrical and Computer Engineering program at the University of New Haven is accredited by ABET's Engineering Accreditation Commission (EAC). As seen in Table 1, a complete list of courses and their connection to embedded systems has been included.

Table 1: Listing of courses within the ECE curriculum which relate to embedded systems.

Course Title	Year Taken	Connection to Embedded Systems
EASC1107: Introduction to Engineering	1st	• Familiarity with microcontrollers • Basic understanding of general-purpose inputs and outputs • Basic level of embedded systems design and programming
CSCI1110: Introduction to C Programming	1st	• First course in computer programming using the C language • Problem solving, algorithm development, logic
ELEC1155: Digital Systems: Logic Design	1st	• Fundamentals of digital systems • Number systems used within embedded devices • Basic analysis and design
EASC2230: Fundamentals and Applications of Analog Devices	2nd	• Principles of electrical devices • Outputs and applications of sensors and other devices
ELEC2247: Electronics 1	2nd	• Basic semiconductor concepts • Designing circuits with semiconductors
ELEC2255: Digital Systems: Hardware Programming	2nd	• Digital systems test instruments, reading schematics • Simulation of embedded systems • Hardware debugging
ELEC3371: Embedded Systems: Microcontrollers	3rd	• Design focus on microcontroller programming • Communication protocols such as UART, SPI, I2C • I/O, interrupts, timers, addressing modes, memory
ELEC3397: Junior Design Experience	3rd	• Application of embedded systems to solve real-world problems • Optimization of a solution utilizing microcontrollers
ELEC4475: Embedded Systems: System on Chip	4th	• Design of system-on-chip embedded systems • Creating an IP Core in a hardware description language • Hardware, bus interaction, memory, design considerations
ELEC4484: Applications of IoT	4th	• Development of IoT systems • Designing device with IoT capabilities • Ability to use microcontrollers for IoT solutions
ELEC4498: Senior Design Experience	4th	• Application of embedded systems to solve real-world problems • Optimization of a solution utilizing microcontrollers

W. Hu states that embedded systems are designed to meet the software and hardware needs of a particular application, thus theoretical teaching is insufficient for development and cultivation of high-level talents [8]. Although the courses in Table 1relate to embedded systems, students struggle to learn the topic, connect topics between courses, and apply those topics to real-world applications thus facilitating a need for Modular Embedded Tools (METs) integrated within an electrical and computer engineering curriculum.

B. Determining Student Motivation and Interest

As described by A. Martin in his publication on The Student Motivation Scale, student performance in any given subject is directly linked to their motivation and interest in that subject, thus any educator attempting to enhance a students' motivation must use a tool which can "efficiently and effectively measure aspects of motivation that reflect its multidimensionality" [9]. The student motivation scale is a series of questions which measure factors which enhance or reduce motivation and achievement behavior, called boosters and guzzlers respectively. Boosters are divided into two categories; booster thoughts which include self-belief, learning focus, and value of schooling, as well as booster behaviors, which include persistence and planning. Guzzlers are also divided into two categories; thoughts/feelings which include anxiety and control, and behaviors which include avoidance and self-sabotage. Students are asked to complete a questionnaire which features questions that specifically target each booster and guzzler. A scale of 1 ('Strongly Disagree') to 7 ('Strongly Agree') is used to allow students to self-assess how well they agree or disagree with a particular question. Data is then collected and analyzed to determine a students' motivation and interest in a subject, in this case the current embedded systems curriculum. Tracking student motivation and comparing between baseline and implementation will be valuable to assess the implementation of a METs system.

C. Determining Course Connections

Curriculums are designed to map content to learning objectives which lead to a student building unique skills to be proficient in their field. Each course within the curriculum has objectives, instruction, and evaluation to educate students and monitor progress towards understanding each topic. For many students, academic work can feel disconnected from real-world challenges and separate from each course within the curriculum. Understanding the current level of connections and ability to solve real-world problems will be essential in determining which direction a new METs system should go. To determine these metrics, an oral assessment is made by interviewing participants on their experience in the courses outlined in Table 1, as well as their ability to make connections to embedded systems. Students are to be asked to describe the relevancy of the course to a project which they have completed that relates to or involves embedded systems. Students who are taking or have completed the Junior and Senior design courses in Table 1 will be asked to describe the real-world problem and how well an embedded system solution would fit. A scale of 1 ('Strongly Disagree') to 7 ('Strongly Agree') is used by the interviewer to evaluate a students' connection between the course and embedded systems to be.

III. Results

Participants for this study were recruited from current and former students of the course titled Embedded Systems: Microcontrollers. This course is offered every semester and as shown on Table 1, is typically taken during the third year of study. By the end of the third year, students should have a strong grasp of the concepts of embedded systems and an ability to apply those concepts to real world problems. In 2022, the University of New Haven has a total of 5,097 undergraduate students with a student body nearly split 50-50 between males and females, with 29.5 percent of students identifying as a member of an underrepresented group. Incoming first year students had an average high school GPA of 3.48. Each participant who volunteered was given a questionnaire to determine motivation and interest, which was then followed up by an interview to evaluate course connections and ability to use embedded systems to solve problems. Table 2 highlights the results of the pre-interview survey. Assignments within a curriculum should maximize booster thoughts and behaviors and minimize guzzler thoughts and behaviors.

Table 2:Pre-Survey results from the fifteen participants detailing average scores for booster and guzzler thoughts and behaviors.

		AVG Score	STD
Booster Thoughts	Self-Belief	92.4	9.1
	Value of Schooling	88.6	15.5
	Learning Focus	96.2	10.1
Booster Behaviors	Planning/Monitoring	73.3	16.1
	Persistence	77.1	16.0
Guzzler Thoughts	Anxiety	73.3	27.5
	Low Control	44.8	25.8
Guzzler Behaviors	Avoidance	76.2	16.8
	Self-Sabotage	73.3	31.9

Average scores were calculated by aggregating participant responses and converting to a score out of 100. Table 3 shows another metric tracked, which is individual level of engagement in hobbyist activities involving embedded systems, such as Arduino, outside of assigned coursework.

Table 3:Results of self-assessed hobbyist engagement outside of required coursework.

	AVG Score	STD
Hobbyist Activities	69.5	22.2

Also tracked in the pre-survey was club involvement, with 20% of participants having some level of involvement in a technical club such as IEEE or the Makerspace. Table 3 highlights the results of the interview conducted after the survey to establish course connections. As all participants were currently or had previously taken Embedded Systems: Microcontrollers, the chosen project for all students was within this course. Along with questions on course connections, questions were posed regarding the student experience with the chosen project. These questions focus on the student experience with solving the project, how long they estimate the project to have taken, and how much help the student required from teaching assistants, online sources, office hours, or other means. Additionally, participants were asked to rate how much of the code was developed independently versus reused or modified from other sources, such as sample code, online sources, or other students. Table 4 also includes a row with the average assessment of independent code development.

Table 4: Interview results detailing average scores for course connections and code development.

	AVG Score	STD
Code	65.7	22.8
EASC1107	20.9	9.4
CSCI1110	74.3	24.9
ELEC1155	51.4	24.0
EASC2230	33.3	21.4
ELEC2247	39.3	23.9
ELEC2255	62.1	26.3
ELEC3397	81.3	22.9
ELEC4452	34.3	23.9
ELEC4497	78.6	26.7

In total, fifteen individuals volunteered to participate in the surveys and interviews. Participants were given the right to not answer or retract an answer from any question, thus average scores may not include responses from all fifteen research subjects. As such, the standard deviation gives an indication of the spread amongst the sample data set within the population.

IV. Discussion

A. Limitations

The pre and post interview datasets come with some limitations. First, students self-selected to participate in the study, thus resulting in a lower quantity of datapoints. The population of students was also limited to those who had completed or were in the process of completing the junior-level embedded systems course, further limiting the number of potential research subjects to study. This was necessary as the targeted curriculum change requires an understanding of the current level of embedded systems knowledge within the student population. A limitation of the pre-interview survey is that the data was derived from self-reports by the participants and does not consider secondary sources such as teacher assessments. Finally, a limitation from the post-interview data comes from the fact that not every student who participated had taken every class which was questioned. This further limits the number of prospective subjects and increases the standard deviation of answers.

B. Pre-Interview Survey Results

Data from the pre-interview survey results in Table 2 indicate a strong level of booster thoughts, but lower booster behaviors. An average of 92.4% in self-belief indicates students have confidence in their ability to complete assignments. An average of 88.6% in value-of-schooling indicates most participants see the value in those assignments and their relevancy to non-academic challenges. An average of 96.3% in learning focus indicates they are willing to focus on learning to solve problems which invigorate them. The lower score of 73.3% for planning/monitoring indicates a lack of clarity to plan their solution for assignments. The score of 77.1% for persistence shows a lack of motivation to keep trying to work out a solution to challenging or difficult assignments. The pre-survey also indicated a higher score for both guzzler thoughts and behaviors. The score of 73.3% for anxiety indicates a level of worry, or a fear of not doing well on their assignments. The lower score of 44.8% for low control indicate the level of clarity students have on what they need to do to succeed. The higher score of 76.2% for avoidance indicates a students' motivation does not come from an interest in the subject or desire to learn, but to avoid a poor grade and the repercussions that grade could have. Finally, the higher score of 73.3% for self-sabotage indicates the student priorities are not on completing their assignments, thus reducing their chances of success. As the goal is to maximize boosters and minimize guzzlers, this data as a whole correlates with the theory that the current curriculum is not optimized to engage, motivate, or inspire curiosity within the students. This lack of motivation and interest directly translates to students struggling to learn embedded systems and apply embedded topics to real-world applications.

C. Post-Interview Results

The post-interview data in Table 4 indicates a weak connection between embedded topics taught in classes and the embedded systems course. The strongest course connections were an average of 74.3% in CSCI1110, which teaches the programming language that the embedded microcontrollers is written, 78.6% in ELEC4497 which is the senior design experience where an embedded system is typically used, and 81.3% in ELEC3397 which is the junior design experience where an embedded system is typically used. The lowest connections came from EASC1107 at 20.9%, and is a course which has the first introduction to embedded systems, and EASC2230 at 33.3%, which gives an overview of the signals and sensors which are commonly used in embedded systems. The strongest connection is coming from courses which have a hands-on approach to learning, where a student is physically coding or building a system which could utilize an embedded system. The courses with the weakest connections follow a traditional theoretical approach to introducing and teaching concepts.

D. Future Considerations

It is evident that courses following a traditional theoretical approach to introducing concepts do not make a strong enough impression on students to carry over to future courses. M.M. Irfan has identified that a paradigm shift to focus on project-based learning over the traditional theoretical approach is required to ensure students are best prepared for industry [10]. Our proposed solution seeks to develop a modular education tool system as the solution to challenges within embedded systems education. This tool system will be comprised of products which demonstrate various embedded systems concepts. Tools will be accompanied with a detailed datasheet and project plan to facilitate seamless integration within a university course. Every tool can be connected together to form a complex system. Tools will be designed to maximize boosters and minimize guzzlers. Research suggests that employers favor experience over education [11], thus having significant hands-on experience with a modular tool system will allow students to be better prepared for the challenges in developing high performance embedded systems. Resulting from these findings, research will be focused on a preliminary design of the tools within the system as well as the correlation to relevant classes within an Electrical or Computer Engineering curriculum.

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