Preliminary Results of Modular Embedded Tool Implementation

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***Abstract*—This work in progress paper reports on research that aims to measure student success in embedded systems upon implementing two educational hardware modules. Extending the research from *Establishing Baseline Data on Student Success in Embedded Systems Education*, the authors found that current projects within the Electrical and Computer Engineering curriculum at the University of New Haven do not sufficiently engage students, educate on embedded topics, nor inspire curiosity for independent learning. Courses following a traditional theoretical approach to embedded systems education do not leave a strong enough impression on students throughout their courses, nor best prepare students for the challenges of working in industry. To remedy these educational challenges, a novel series of Modular Embedded Tools (METs) has been developed to increase student competency, motivation and interest, level of independent ability to complete project assignments, their connection of embedded systems to other disciplines, and student readiness to solve real-world problems. Each tool has a design function targeting specific aspects of electrical engineering and embedded systems. Accompanying each designed tool are a series of projects to educate on the targeted subject. This paper presents data collected from the 2022-2023 academic year, highlighting the result of administration of new projects utilizing circuit boards named MET1155 and MET2230. Each of these tools focuses on a particular aspect of electrical engineering and embedded systems. MET1155 educates on digital systems concepts and general-purpose input and output manipulation and was implemented in the course titled Digital Systems: Logic Design. MET2230 educates on operational amplifiers and analog-to-digital conversions and was implemented in the course titled Fundamentals of Analog Circuits. Both modules were also introduced in the course titled Embedded Systems: Microcontrollers. The data was collected through surveys and semi-structured interviews administered within those courses. The findings show that utilizing these tools resulted in an increase from the baseline dataset in student motivation, engagement, and ability to problem solve utilizing embedded systems. Resulting from these findings, the data presented has informed the next step of expanding the quantity of tools to cover additional embedded topics.**

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

I. INTRODUCTION

Embedded systems are an integral part of modern society. As mentioned by W. Hu et al, rapid development of semiconductors has resulted in an explosion in the development of technology, as well as a plethora of emerging applications, utilizing embedded devices [1]. Development of these systems require significant knowledge and experience to successfully design a commercial or industrial product utilizing embedded systems. 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 [2], connecting embedded systems to other disciplines, preventing code-copying, and encouraging engagement, development, and reuse of code [3], as well as general student motivation, interest, and competency in the subject.

A case study of University of New Haven students enrolled in the Electrical and Computer Engineering curriculum determined that courses following a theoretical approach to teaching concepts do not sufficiently motivate students, educate on embedded topics, nor inspire curiosity for independent learning [4]. Nine Electrical and Computer Engineering courses were targeted for the study as they contain pertinent topics to embedded systems. The target population was interviewed using a series of questions developed following the motivation theory framework outlined by A.J. Martin [9]. The questions developed in [4] determine a student's motivation and connection of topics to embedded systems. As shown in Table 1, the findings support the hypothesis that theoretical-based courses performed lower than project-based courses in terms of student motivation and connection of topics to embedded systems. Average scores were calculated by aggregating participant responses using a 7-point Likert scale, where a higher score represents a stronger connection between embedded topics. The single-factor ANOVA yielded a near-zero probability value of 7.0E-13, indicating the difference between the dataset answers is not by random chance, but rather by the nature of the type of course as theorized in our hypothesis.

Table 1: Single Factor ANOVA between student responses for Hands-On and Theoretical courses. Project based courses yielded higher average scores for motivation and connection to embedded.

Groups	*Count*	*Average*	*Variance*
Hands On	50	5.16	3.17
Theoretical	62	2.56	2.57

F	*P-value*	*F crit*
66.1	7.0E-13	3.9

I. Martinez postulates that student motivation and engagement can be increased by giving complex and meaningful challenges [5]. W. Hu et al proposed a project-based learning framework for embedded systems education by focusing on embedded technologies within the classroom. Our team seeks to develop a Modular Embedded Tool (MET) system as a project-based approach of addressing the challenges encountered when teaching embedded systems within the curriculum. The first two of nine courses targeted for this study were Digital Systems: Logic Design and Fundamentals and Applications of Analog Devices. While these courses are specific to University of New Haven, the pertinent topics appear within the curriculum of any program accredited by ABET. A MET developed for these courses would then be utilized in Embedded Systems: Microcontrollers. The intended outcome of these modules is to increase student motivation using an educational tool which is engaging, easy to use, and inspires curiosity while educating on embedded topics. This contribution to engineering education will allow instructors to increase student competency and motivation by implementing these modules throughout their curriculum.

II. Methodology

A. Framework

K. Doulougeri noted that students appreciate real life aspects to challenges and confirmed that student motivation increased when they were presented challenges relevant to their professional development [6]. Embedded systems deal with physical systems interfacing to solve industry challenges. Project-based learning frameworks have become a growing trend in education as the hands-on experiential learning provides a student-directed learning systems that mimic industry challenges. In 2011, C. Maida postulated that challenges with the rapid increase in technology should shift the emphasis of education toward a project-based approach [7]. He states, "project-based learning challenges students by acknowledging their roles as participants engaged in producing knowledge [and] helps to develop habits of mind associated with personal and occupation success." The project-based learning framework in [8] focuses on a mechanical engineering project which requires a practical design solution. The methodology behind both tools studied in this paper (MET1155 and MET2230) follow this methodology to increase student ability to implement knowledge learned in previous courses for solving embedded challenges. While [8] focuses on mechanical engineering, MET devices focus on embedded systems. These devices are to be used by an educator by providing students a project-based learning tool which relates to embedded systems and mimics a device which they may encounter in industry. B. Sababha et al discuss the importance of project-based learning to enhance embedded systems education [10]. They specifically target a course in embedded systems fundamentals with a series of projects catered to the course outcomes. By the end of the study, they found that the project-based approach increased student interest and engagement in the subject, as well as gave a better representation of real-world problems. Our MET system is designed to expand the scope of these projects from a single course to a curriculum wide series of projects which connect the topics of each course together.

B. MET1155

The course Digital Systems: Logic Design instructs students on the fundamental concepts of digital systems such as binary numbers, combinational logic, components such as multiplexers, and analysis of synchronous circuits. To properly educate on these topics, careful consideration for the circuit design and interface was taken to develop a circuit board capable of educating on fundamental concepts, as well as being relevant to embedded systems. The circuit consists of a binary coded decimal to seven segment decoder, wired to two displays, whose grounds are switched by a multiplexer. This device is capable of operating as a stand-alone product or as part of a larger system. Both male and female headers are included to interface to a multitude of embedded systems development kits, such as the EasyMX Pro from MikroElectronika or the Xilinx Arty S7 from Digilent. Figure 1 shows an operational board connected to an Arty S7 development board. Within the Digital Systems course, an associated project requires students to analyze the MET1155 schematic, and develop the theoretical output within a truth table, solve by using Karnaugh maps, then verify the truth table on the physical MET1155 device by toggling the DIP switches to match the input states of their truth table. Success is measured by how well the theoretical output matches the actual output. The output state should include all numerals being shown on both displays, one display at a time, as selected by the included multiplexer.

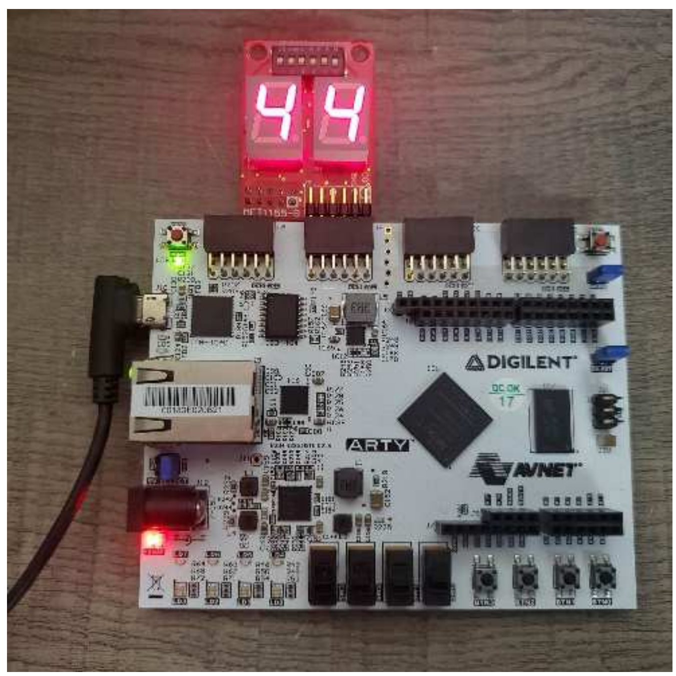

Figure 1: MET1155 plugged into Arty S7 development board, programmed to output '44' on the display.

Within the Embedded Systems: Microcontrollers course, an associated project requires students to draw the theoretical schematic to interface the MET1155 PCB to an STM32F107VC microcontroller, modify the MET1155 truth table to reference the microcontrollers' general-purpose input and output pins, and then physically connect the MET1155 device to the target embedded system and write software to display numerals on both displays. Success is determined by the student's ability to utilize the microcontroller to automatically cycle through all numbers on both displays automatically. Students must be able to analyze the MET1155 schematic, understand the components, and be able to develop a truth table showing the theoretical output, thus tying in knowledge from the Digital Systems: Logic Design course. Due to the versatility of the design, the MET1155 device can be utilized in a variety of other projects and courses. The included datasheet contains a full schematic, truth tables, header pin outs, and a mechanical drawings to allow ease of use and integration into other subjects.

C. MET2230

Topics within the Fundamentals of Analog Devices course relate to the fundamental principles of analog devices, including operational amplifiers and sensors, as well as the necessary techniques to analyze circuits containing these devices. As with the Digital Systems: Logic Design course, to properly educate on these topics, careful consideration for the circuit design and interface was taken to develop a circuit board capable of educating on fundamental concepts, as well as being relevant to embedded systems. The circuit consists of a light dependent resistor (LDR) in a quarter-bridge configuration as an input to an inverting differential amplifier, whose output is sent to a light emitting diode (LED). Both male and female headers are included to interface to a multitude of embedded systems development kits, such as the EasyMX Pro from MikroElectronika or the Xilinx Arty S7 from Digilent. Figure 2 shows an operational board connected to an EasyMX Pro V7 for ARM development.

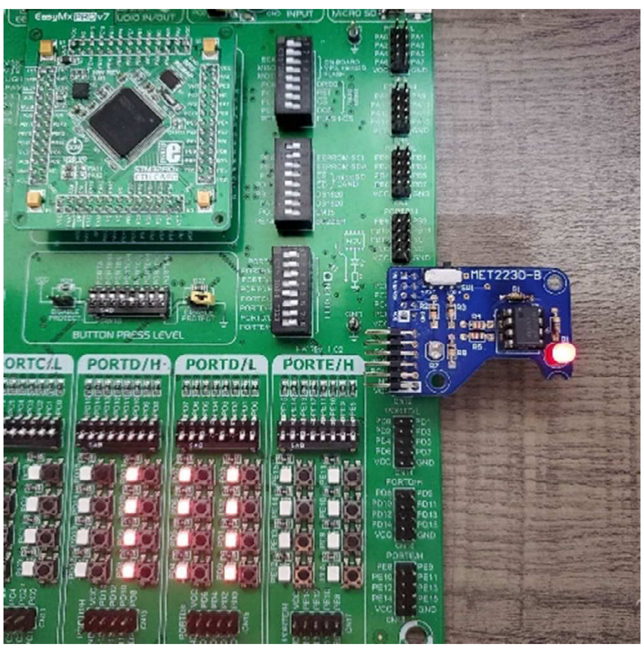

Figure 2:MET2230 plugged into an EasyMx Pro for ARM development board.

Within the Fundamentals of Analog Devices course, an associated project requires students to analyze the MET2230 schematic to determine the equation for output current based on the varying LDR input. Using this equation, they can graph current versus resistance in order to infer output LED brightness versus light presence. Once those calculations are complete, they are tasked to physically build and solder the components onto the board to build the circuit, then test it by powering the PCB and covering the LED, observing how the amount of light allowed influences the brightness of the LED. Success with this project requires the student to successfully solder the PCB, and observe the same relationship between light and resistance as calculated.

Within the Embedded Systems: Microcontrollers course, an associated project requires students to draw the theoretical schematic to interface the MET2230 PCB to an STM32F107VC microcontroller, calculate the expected analog-to-digital (ADC) conversion values based upon the PCB output, then physically connect the MET2230 device to the target board and write software to read the analog voltage from the PCB while varying the amount of light present. Success with this project is determined by the student's ability to derive the theoretical output of the MET2230 PCB and program the PCB to read in the analog value. As with the MET1155 device, the MET2230 device can be utilized in a variety of other projects and courses, and includes a datasheet with a full schematic, output graphs, header pin outs, and mechanical drawings.

D. Determining Results

To establish the level of connection and ability to solve real-world problems after completing a MET project, an oral assessment is made by interviewing participants on their experience in the course as to determine their ability to make connections to embedded systems. Students are asked to explain the project and describe the relevancy to its' associated course. During the interview, the same questions which were asked to baseline participants in [4] were asked to participants who utilized the MET projects. The results form the basis for comparison between students who did not utilize the MET system for education, and those who did. Questions are of the form 'Knowledge from [Course] was relevant and helpful to this project.' A Likert scale of 1 ('Strongly Disagree') to 7 ('Strongly Agree') is used by to evaluate the student's connection between the course and embedded systems. Scoring is determined by how well the student articulates the topics under question during the interview. Paired with the projects are rubrics to assess the technical ability of the students and assign an evaluation grade.

III. Results

Participants for this study were recruited from current students within the courses Digital Systems: Logic Design, Fundamentals and Applications of Analog Devices, and Embedded Systems: Microcontrollers. In total, twenty-eight 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 research subjects. Average scores were calculated by aggregating participant responses and converting to a score out of 100. Analysis of variance was performed to determine the probability of participant responses resulting from random chance rather than module implementation.

A. MET1155 Implementation

Table 2 details the data summary and analysis of variance comparing the baseline data from [4] with the population which utilized the MET1155 device. Participants who used MET1155 scored 74% higher than baseline participants in their level of knowledge of Digital Systems and connection to embedded systems. The single-factor ANOVA yielded a probability value of 3.79E-04, therefore we conclude the difference between the datasets support the hypothesis by indicating a near-zero probability of the data being a result of random chance.

Table 2: Data from MET1155 Implementation within the Digital Systems course.

Digital Systems Groups	*Count*	*Average*	*Variance*
Baseline	15	51.4%	40.4%
With MET1155	8	89.3%	7.1%

F	*P-value*	*F crit*
17.85	3.79E-04	4.3

B. MET2230 Implementaiton

Table 3 shows the data summary and analysis of variance comparing the baseline data in [4] with the population which utilized the MET2230 device. Participants who used MET2230 scored 158% higher compared to the baseline participants in their level of knowledge and connection to embedded systems. The single-factor ANOVA yielded a probability value of 6.80E-06, therefore we conclude the difference between the datasets support the hypothesis by indicating a near-zero probability of the data being a result of random chance.

Table 3: Data from the MET2230 Implementation within the Fundamentals and Applications of Analog Devices course.

Analog Devices Groups	*Count*	*Average*	*Variance*
Baseline	15	33.3%	32.0%
With MET2230	5	88.6%	24.3%

F	*P-value*	*F crit*
26.47	6.80E-05	4.4

C. Student Motivation

Discussed in [4], student success in a given subject is tied to their motivation. AJ Martin separates student motivation into factors that enhance motivation, called boosters, and reduce motivation, called guzzlers [9]. An 'ideal' scoring would see a maximum in boosters and a minimum in guzzlers, meaning they are perfectly motivated and have no detractors in motivation and achievement. In comparing the population which utilized the implemented modules with the baseline data gathered in [4], booster thoughts for self-belief and learning focus did not significantly increase or decrease, however, value of schooling significantly increased. Booster behaviors for planning/ monitoring and persistence increased. Guzzler thoughts for anxiety and low control significantly increased. Guzzler behaviors significantly decreased.

Table 4: Data comparison of student responses for booster and guzzler thoughts and behaviors.

		AVG Score (Baseline)	AVG Score (Implementation)
Booster Thoughts	Self-Belief	92.4%	92.3%
	Value of Schooling	88.6%	97.8%
	Learning Focus	96.2%	96.7%
Booster Behaviors	Planning/Monitoring	73.3%	82.4%
	Persistence	77.1%	83.5%
Guzzler Thoughts	Anxiety	73.3%	86.8%
	Low Control	44.8%	56.0%
Guzzler Behaviors	Avoidance	76.2%	67.0%
	Self-Sabotage	73.3%	63.7%

IV. Discussion

A. Limitations

One limitation of this study is in the dataset size. The population of students was limited to those who had completed projects for both the module under test and the Embedded Systems: Microcontroller course, thus resulting in a lower quantity of potential research subjects. This study focuses on a specific subset of a much broader field, and at present is a pilot study conducted at a single university. While ANOVA is valuable for small datasets, there is an increased sensitivity to the normality assumption at a low sample size. Additionally, the data for the pre-interview survey was derived from self-reports and does not consider secondary sources such as teacher assessments.

B. Results

As shown in Table 2 and Table 3, the implementation of both modules resulted in a significant increase from the baseline. Despite limitations in population, the analysis of variance provides a convincing argument that the increase in student success is a result of module implementation and not stochastic process. Both MET1155 and MET2230 tools provide a hands-on project-based learning approach to concepts which connect with embedded systems. The findings support the hypothesis that utilizing modular embedded tools increase student ability to problem solve and connect course content.

Modules are intended to increase student motivation and interest in the subject by increasing booster thoughts and behaviors and minimizing guzzler thoughts and behaviors. Table 4 shows that implementation of the modules gave relevancy to the topics in question, thus improving the perceived value of schooling. Further, the modules increased student planning/monitoring as well as persistence. Finally, guzzler behaviors of avoidance and self-sabotage were reduced, however guzzler thoughts did increase. The net result in comparison to the baseline shows a significant increase in motivation and interest, which is validated by the data shown in Table 2 and 3. The increase in guzzler thoughts is concerning, however, this can be explained by a perceived increase in the stakes of a project-based assignment. AJ. Martin notes that guzzler thoughts derive from a fear of failure and a need to be successful [9].

C. Future Considerations

With the success of the MET1155 and MET2230 implementations, future research will focus on the design of additional modular embedded tools for courses identified in [4]. Special consideration to project design should focus on reducing guzzler thoughts to increase student motivation. Martin suggests that they can be reduced by emphasizing learning from failure and increasing student control by better connecting their effort to academic outcomes [9]. Further, future research with a larger and more diverse sample could provide additional insights into the implementation of modular embedded tools. This could include examining how the implementation affects different subgroups, such as students from underrepresented backgrounds or with learning disabilities. Overall, the findings of this study suggest that modular embedded tools have the potential to positively impact learning and motivation, and future research will expand the quantity of tools to broaden that impact. These modules provide an easy-to-use learning tool which accurately represents a circuit which they may encounter in a professional environment. The innovation of the MET system has the potential to provide students with a hands-on experience to best prepare for the challenges of industry.

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