Enhancing Embedded Systems Education through Modular Embedded Tools: Bridging Theory, Practice, and Pedagogy

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Abstract

Embedded systems education is essential for preparing engineers in industries such as consumer electronics, automotive, and medical devices. However, traditional coursework often emphasizes theoretical instruction over hands-on experience, leading to gaps in student engagement, knowledge retention, and problem-solving skills. This dissertation proposal introduces Modular Embedded Tools (METs), a project-based learning approach that integrates structured, hands-on projects across multiple embedded systems courses to bridge the gap between theory and practice.

This study is guided by three frameworks: Motivation Theory, Project-Based Learning (PBL), and Technological Pedagogical Content Knowledge (TPACK). A mixed-methods approach is used, incorporating quantitative and qualitative assessments, including pre- and post-assessments, student motivation surveys, and coding proficiency evaluations across multiple ABET-accredited engineering courses.

Preliminary findings indicate that MET-based learning significantly improves student engagement and performance. Post-intervention assessments reveal a 74% increase in digital systems competency ($p = 2.01E-11$) and a 166% improvement in analog circuit comprehension ($p = 7.05E-13$). Statistical analysis confirms that these improvements are not due to random variation. Additionally, students report higher motivation, increased confidence in problem-solving, and stronger connections between coursework and real-world applications.

This research contributes to engineering education reform by providing a validated instructional model that can be scaled across institutions. Future work will focus on expanding MET implementation, refining instructional strategies, and exploring interdisciplinary applications of hands-on embedded systems education.

Introduction and Problem Statement

Embedded systems are a fundamental part of modern engineering, playing a critical role in industries ranging from consumer electronics to automotive and medical devices. As defined by T. Noergaard, an embedded system refers to electronic equipment with a computing core limited in hardware and software which is designed to meet a specific function [1]. Designing an embedded system that balances energy efficiency, cost-effectiveness, reliability, compactness, and execution performance is a complex yet essential skill for electrical and computer engineers. Consequently, embedded systems play a crucial role in electrical and computer engineering curriculums. **However, traditional embedded systems education often fails to sufficiently engage students, inspire curiosity, or promote independent learning.** The rapid growth of embedded systems in industry demands engineers who are well-versed in both theoretical foundations and practical applications. Unfortunately, **global education in this field has not kept pace with technological advancements, leading to a gap between academic training and industry expectations.** Hu et al. (2020) highlights that traditional embedded systems courses emphasize theory over hands-on experience, leaving graduates underprepared for industry demands [2].

Traditional sciences such as physics, health, and chemistry have been developed through centuries of research and implementation. Electrical engineering, and in particular the concentration of embedded systems, has a less storied history [8]. **Current embedded systems**

education at the University of New Haven, as well as other ABET-accredited programs, **primarily follow a theoretical teaching approach**, not dissimilar to teaching practices of other sciences. University of New Haven courses covering embedded systems, including Introduction to Engineering, Digital Systems: Logic Design, Fundamentals of Analog Circuits, Embedded Systems: Microcontrollers, System-on-Chip Design, and Senior Design, which are similar to courses at other universities, frequently lack the hands-on, highly motivating, project-based learning that students need to reinforce concepts effectively. Current projects within the curriculum do not sufficiently engage students, educate on embedded topics, nor inspire curiosity for independent learning. As highlighted in prior research (Pellicano et al., 2022), **it is evident that courses following a traditional theoretical approach are not sufficient** [3]. Students in embedded systems courses often struggle with translating fundamental theory to practical applications [4], making interdisciplinary connections between embedded systems and other engineering fields [5], maintaining motivation and engagement [3], developing and reusing code independently [6], as well as general student motivation, interest, and competency in the subject. These challenges have led to a shortage of highly skilled engineers capable of designing and developing embedded devices across various industries [7].

To address these challenges, this research proposes the development and implementation of **Modular Embedded Tools (METs), a novel project-based learning system designed to increase student engagement, motivation, and competency in embedded systems education.** The MET system consists of hardware modules paired with structured learning projects aimed at:

- Strengthening students' ability to connect theoretical knowledge between supporting fundamental courses outside of embedded systems to embedded topics.
- Apply theoretical principles to solve real world applications.
- Providing real-world problem-solving experiences that mimic industry challenges.
- Encouraging independent learning.
- Ensuring seamless integration into an ABET-accredited ECE curriculum.

The research presented in this dissertation proposal will examine prior findings on MET-based learning across multiple embedded systems courses and explore the next steps for improving embedded systems education. By leveraging motivation theory and project-based learning principles, this proposal aims to outline the methods for enhancing student engagement, competency, and curriculum integration to ensure that graduates are well-prepared for the evolving demands of the industry.

Research Questions and Objectives

This dissertation proposal is guided by the following key research questions divided into two categories. The first category is in regard to **understanding the current state of embedded systems education.** This is essential for identifying key challenges and areas for improvement. The following questions aim to establish baseline data on student motivation, knowledge retention, and coding proficiency within the existing curriculum.

- How motivated and interested are students in embedded systems education within the current curriculum?

- How well do students in the current curriculum retain embedded systems knowledge from previous courses, apply theoretical principles to hands-on projects, and make interdisciplinary connections?
- How well do students in the current curriculum develop embedded systems code independently?

Once baseline data is established, **the next phase of this research will focus on evaluating the impact of MET-based learning.** These questions will examine whether METs successfully enhance engagement, strengthen interdisciplinary applications, and promote independent coding skills. Additionally, they will explore strategies for effectively integrating METs into a structured engineering curriculum. These questions will help determine whether METs improve student engagement, understanding, and independent coding abilities. Additionally, they explore the feasibility of integrating METs into the broader engineering curriculum.

- How well can students apply theoretical principles to practical applications after exposure to MET-based learning?
- What effect does MET-based learning have on students' ability to make interdisciplinary connections between embedded systems and other engineering disciplines?
- What strategies can be used to effectively integrate METs into an ABET-accredited electrical and computer engineering curriculum?

To address these research questions, **this study aims to achieve the following objectives**:

- Evaluate the current state of student engagement, motivation, and competency in embedded systems education by conducting pre-implementaiton assessments.
- Develop and implement a MET-based instructional framework grounded in motivation theory and project-based learning (PBL) to enhance hands-on, experiential learning in embedded systems education.
- Measure the effectiveness of MET-based learning using quantitative and qualitative metrics such as academic performance, student feedback, and knowledge retention assessments.
- Identify best practices for integrating METs into an ABET-accredited electrical and computer engineering curriculum to ensure long-term sustainability and widespread adoption.

By addressing these objectives, this research will contribute to the enhancement of embedded systems education, ensuring that students acquire both the theoretical knowledge and practical skills required to succeed in the field.

Theoretical Frameworks

The theoretical foundation of this study is based on key educational frameworks that support the implementation of MET-based learning. **Motivation Theory [9], Project-Based Learning (PBL) [13], and Technological Pedagogical Content Knowledge (TPACK) [16]** are frameworks which provide the foundation for elevating the impact of METs on student engagement, competency, and curriculum integration.

Motivation Theory

Motivation is a fundamental driver of student engagement and academic success. 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]. Martin's **Student Motivation Scale** provides a structured approach to assessing and enhancing motivation in educational settings. Motivation Theory **classifies student behaviors into enhancing (boosters) and retracting (guzzlers) motivational factors**, which directly influence learning outcomes.

The **five booster factors that contribute positively** to student learning include:

- *Self-belief:* A student's confidence in their ability to succeed in coursework.
- *Value of schooling:* The perceived importance of education in achieving long-term goals.
- *Learning focus:* A desire to deeply understand content rather than simply completing assignments.
- *Planning and monitoring:* The use of structured approaches to track progress and set academic goals.
- *Persistence:* The ability to continue working through difficulties.

Conversely, the **four guzzler factors negatively impact student motivation** and performance:

- *Anxiety:* Excessive worry about performance, leading to decreased learning efficacy.
- *Low control:* The belief that success or failure is beyond the student's control.
- *Avoidance behaviors:* Engagement in coursework solely to prevent failure rather than to learn.
- *Self-sabotage:* Actions such as procrastination that reduce the chances of success.

Traditional embedded systems courses are heavily theory-based, often lacking interactive, hands-on components that reinforce student engagement. **The METs approach aims to enhance student motivation by addressing both booster and guzzler factors**. METs encourage self-belief and learning focus through real-world, interactive embedded projects, reduce anxiety and avoidance behaviors by offering structured skill-building activities that make complex topics more approachable, and enhance students' perceived value of education by aligning coursework with industry-relevant applications.

Martin outlines a series of questions which measure factors that enhance or reduce motivation and achievement behavior. Students are asked to complete a questionnaire which features questions that specifically target each booster and guzzler. An example of a booster question is "I feel very pleased with myself when I really understand what I am taught in school". An example of a guzzler question is "I tend to put off doing assignments until the last minute." The full list of questions is detailed in [9]. A Likert 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. By implementing METs, this study will apply the motivational framework to measure changes in student motivation, providing quantitative validation of METs' effectiveness in improving engagement and learning outcomes.

Recent research suggests that motivation-based interventions can have a significant impact on at-risk students. Sisk et al. (2018) conducted a large-scale meta-analysis examining the link between growth mindset and academic achievement, concluding that growth mindset alone has a weak correlation with academic success ($r = 0.10$), but its effects are more pronounced in younger students and those from disadvantaged backgrounds. Their findings suggest that **while motivation is critical to learning outcomes, interventions must be structured and reinforced** with hands-on learning experiences to be effective [10]. This aligns with **the MET-based approach, which seeks to increase student motivation through structured, industry-relevant, hands-on learning** rather than relying solely on mindset interventions.

Project Based Learning

One of the most effective ways to **reinforce motivation and engagement in engineering education is through Project-Based Learning (PBL) [13], an instructional method that immerses students in hands-on, problem-solving experiences** that mirror real-world engineering challenges. Unlike traditional lecture-based instruction, which often emphasizes passive knowledge absorption, PBL requires students to actively apply their knowledge to solve complex, interdisciplinary problems.

PBL has its roots in constructivist learning theory, which posits that learners construct knowledge through experiences and active engagement rather than passive instruction. John Dewey's progressive education model was one of the earliest advocacies for experiential learning, describing schools as “social laboratories” where students engage in meaningful inquiry and hands-on problem-solving [18]. Dewey’s philosophy has since influenced modern student-centered pedagogies, leading to the development of PBL as a structured learning methodology [12]. Over the years, **PBL has been widely adopted in STEM education, particularly in engineering**, where students must apply theoretical knowledge to real-world scenarios. Studies have consistently shown that PBL enhances problem-solving abilities, increases knowledge retention, and fosters deeper engagement [13]. Engineering education programs increasingly recognize the importance of simulating industry environments, allowing students to work on complex projects that require interdisciplinary collaboration [11]. **The core principles that define PBL** include:

- *Hands-on problem solving:* Students engage in physical, and ideally industry relevant, challenges rather than textbook problems.
- *Collaborative Learning:* Projects often require teamwork where collaboration is essential.
- *Integration of Theory and Practice:* Students bridge the gap between academic learning and application, ensuring they internalize engineering principles rather than memorizing formulas

Research has demonstrated that PBL enhances student motivation, teamwork, and the ability to navigate complex engineering problems [11], [12], [13]. However, **traditional embedded systems education remains highly theoretical, often lacking the structured, hands-on experiences needed to develop practical hardware and software skills**. Furthermore, a lack of physical interaction with real systems can hinder a student's ability to retain information between courses.

One of the key takeaways from F. Craik and R. Lockhart's research on memory retention is that **students are more likely to retain information when they can actively relate it to prior experiences** [14]. This finding reinforces the importance of repeated, hands-on exposure to embedded systems throughout a curriculum. **MET-based learning addresses this gap by integrating structured, hands-on projects across multiple courses, reinforcing memory retention through repetition,** physical interaction, and real-world context. The MET system utilizes PBL principles by providing a modular hardware platform that allows students to interact with embedded systems, integrates structured projects that use similar hardware but gradually increase in complexity, reinforcing previously learned concepts, emphasize real world applications, and require students to develop independent problem-solving skills.

Technological Pedagogical Content Knowledge

Effective project-based learning in embedded systems education will require the seamless integration of technology into education. Mishra and Koehler (2009) argue that **merely introducing technology into the classroom is insufficient; teachers need a deep understanding of how technology interacts with both pedagogy and content to create effective and meaningful learning experiences [15].**

The Technological Pedagogical Content Knowledge **(TPACK) framework provides a structured approach to achieving this integration** by emphasizing the interdependent relationship between content, pedagogy, and technology. It asserts that successful technology integration in education requires an interconnected understanding of three core knowledge domains: **content knowledge** (CK)**, pedagogical knowledge** (PK)**, and technological knowledge** (TK). Rather than treating these elements as separate entities, TPACK emphasizes that effective teaching with technology depends on how pedagogy, content, and technology interact within a specific educational context [16].

Traditional models of teaching often treat technology as an isolated component, without considering its impact on both pedagogy and content delivery. TPACK recognizes that technology is not merely an instructional supplement but a core component of how knowledge is represented and taught. Different technologies afford different ways of teaching content, influencing student engagement, knowledge retention, and learning experiences. As technology rapidly evolves, educators must develop adaptive strategies to ensure students gain relevant, hands-on experience with modern tools [16]. Mishra & Koehler (2013) emphasize that simply adding technology to the classroom is insufficient—teachers must understand how technology, pedagogy, and content interact to create effective learning experiences [16].

In the context of embedded systems education, CK, PK, and TK must be carefully aligned to create an effective and structured learning experience. **CK represents the fundamental concepts of embedded systems,** including microcontrollers, digital logic, analog circuits, and hardware-software interfacing. **PK refers to the instructional strategies that best enhance student learning**, such as project-based learning (PBL), hands-on experimentation, and iterative problem-solving. **TK encompasses the technological tools and software used in embedded systems**

education, including development kits, simulation environments, and debugging tools that provide students with hands-on industry-relevant experience.

The METs system applies TPACK principles by ensuring that all three knowledge areas are effectively integrated. **Modules reinforce CK by incorporating circuit designs** and **programming exercises** aligned with traditional embedded systems coursework. Each module includes lecture materials, assignments, and **structured projects built upon PBL principles,** ensuring that PK is fully implemented. **TK is carefully selected and integrated through hardware platforms**, embedded programming tools, **and real-world engineering applications** that support learning objectives and industry expectations. By aligning CK, PK, and TK, MET-based learning is not merely an application of technology but a structured pedagogical framework that enhances student understanding, improves engagement, and ensures curriculum relevance to the evolving needs of embedded systems engineering.

METs Learning Modules

The METs Learning Modules were developed as hands-on educational tools designed to bridge the gap between theory and practice in embedded systems education. These modules follow project-based learning (PBL) principles and align with Technological Pedagogical Content Knowledge (TPACK) by integrating hardware, instructional strategies, and industry-relevant technology into structured learning experiences. To date, **two modules have been developed and incorporated into six relevant courses** shown in Table 1, either directly or indirectly, at the University of New Haven.

Table 1: Courses with direct or indirect MET-Based Learning intervention.

Course Code and Title	Description	Module
ELEC1155: Digital Systems: Logic Design	Fundamental concepts of digital systems. Direct intervention.	MET1155
EASC2230: Fundamental Applications of Analog Devices	Fundamental concepts of analog systems. Direct intervention.	MET2230
ELEC3356: Digital Systems: Hardware Programming	Design of complex synchronous systems. Direct intervention.	MET1155
ELEC3371: Embedded Systems Microcontrollers	Design of embedded systems. Direct intervention.	MET1155, MET2230
ELEC3397: Junior Design Experience	University driven design sequence culminating up to the junior level undergraduate engineering experience. Indirect intervention.	MET1155, MET2230
ELEC4497/ELEC4498: Senior Design Capstone	Industry driven design sequence culminating the entire undergraduate engineering experience. Indirect intervention.	MET1155, MET2230

Module A: MET1155

Starting with MET1155 module, it is an educational circuit board designed to teach binary-coded decimal (BCD) to 7-segment decoding, truth tables, and multiplexing concepts. The board features two high-brightness 7-segment displays, a BCD to 7-segment decoder, and a 1:2 multiplexer, allowing students to explore how digital circuits control numerical displays. This device can function as a stand-alone product or as part of a larger embedded system. It includes both male and female headers to interface with a variety of development kits, such as the EasyMX Pro from MikroElectronika and the Xilinx Arty S7 from Digilent. Figure 1 shows an operational MET1155 module connected to an Arty S7 development board.

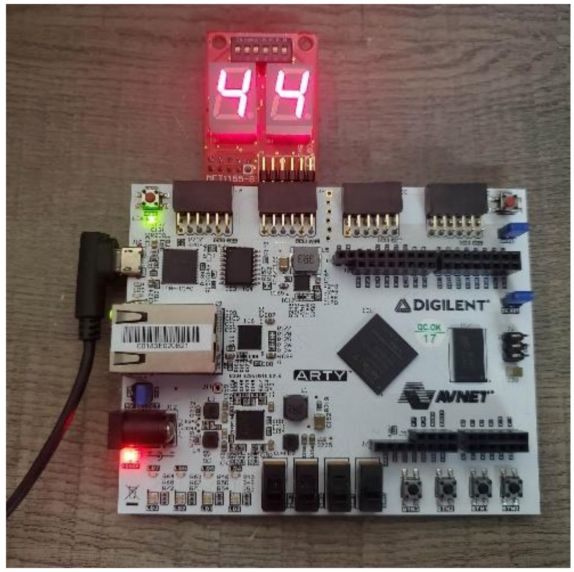

Figure 1:MET1155 plugged into Arty S7 development board, programmed to output '44' on the display.

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. In Digital Systems courses, students use the MET1155 module to explore fundamental concepts of truth tables, binary coded decimals, and combinational circuit design. One of the introductory projects requires students to derive the truth table for the 7-segment display, implement it in a circuit simulation tool, and verify the output against expected numerical representations. A subsequent project expands on this by introducing Karnaugh maps to minimize logic expressions, reinforcing how hardware design can be optimized.

In Microcontroller courses, MET1155 is incorporated into a microcontroller-based project, where students connect the module to an STM32 or equivalent development board and control the 7-segment display using GPIO programming. This **project introduces students to register-based manipulation of hardware**, requiring them to write code that updates the display based on user input or sensor data. An advanced version of this project introduces multiplexing techniques, where students programmatically switch between the two displays using a time-division approach, simulating real-world embedded applications like digital clocks and multi-digit counters.

Additionally, MET1155 has been integrated into hardware-software co-design experiments, where students implement the display logic on an FPGA using VHDL. This enables them to compare software-based and hardware-based implementations of numerical displays, reinforcing the importance of choosing the right hardware architecture for a given application. Through these projects, the MET1155 module not only reinforces theoretical digital design concepts but also provides students with practical, hands-on experience in embedded systems, microcontroller programming, and FPGA-based implementations.

Module B: MET2230

The next module, MET2230, is an educational circuit board designed to teach operational amplifier (op-amp) circuits, Wheatstone bridge configurations, and light-sensitive applications. This module introduces students to analog signal processing and control systems by demonstrating how an op-amp can amplify and respond to light variations in a circuit.

The board features a light-dependent resistor (LDR) in a quarter-bridge configuration, an adjustable gain stage using a TI 741 op-amp, and a visual output indicator (LED) that adjusts brightness based on light intensity. The MET2230 can function as a stand-alone circuit or be interfaced with embedded systems platforms such as Arduino, STM32, and FPGA development boards. Figure 2 shows an operational board connected to an EasyMX Pro V7 for ARM development.

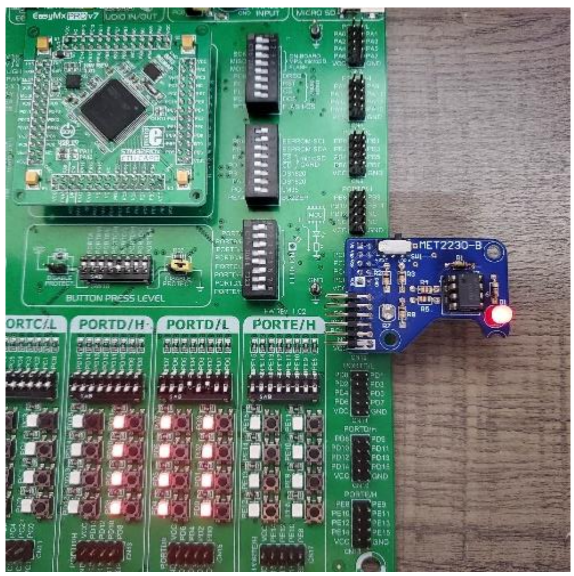

Figure 2: MET2230 plugged into an EasyMx Pro for ARM development board.

The **primary learning objective of MET2230 is to reinforce the fundamental principles of analog electronics** while providing students with hands-on experience designing and testing circuits that respond to real-world inputs. Through its switchable configuration, the module supports two operation modes, 1) LDR mode using the on-board Wheatstone bridge, and 2) External Mode, allowing students to connect their own differential signal, such as a strain gauge, for testing.

In analog circuit courses, students begin by analyzing the MET2230 circuit schematic and performing theoretical calculations to determine expected voltages and currents at various light levels. One of the first assignments requires students to derive nodal equations for the Wheatstone bridge circuit and simulate it using Multisim or SPICE-based tools. A follow-up project requires students to physically assemble the MET2230 module, take experimental measurements, and compare real-world results to theoretical predictions. Through this process, students gain a deeper understanding of how circuits are built, as well as how real-world conditions affect analog circuit performance.

An advanced application of MET2230 involves solar tracking systems, where students use the module to control a motorized solar panel based on light intensity changes. The op-amp output is connected to an embedded system, which adjusts the panel's angle to maximize sunlight exposure. This project reinforces the interdisciplinary nature of embedded systems, combining analog circuits, microcontroller programming, and mechanical automation. Through these projects, the MET2230 module bridges the gap between theoretical circuit analysis and practical hardware design, ensuring that students develop the problem-solving skills necessary for real-world engineering applications.

Methodology

This **dissertation proposal incorporates both quantitative and qualitative data to evaluate the impact of METs** on student engagement, knowledge retention, interdisciplinary connections, and coding proficiency. The study is conducted across multiple electrical and computer engineering courses that include embedded systems topics. **A pre and post implementation will be used to measure changes in student motivation, learning outcomes, and problem-solving abilities** before and after exposure to MET-based learning. Students will be divided into two groups, the control group, consisting of students who complete traditional embedded systems coursework without MET-based learning, and the experimental group, consisting of students who engage with MET-based learning. By comparing student performance, engagement, and retention between these groups, this study aims to quantify the effectiveness of MET-based learning and its alignment with PBL, TPACK, and Motivation Theory frameworks.

Before MET-Based Learning Implementation

Before MET implementation, baseline data will be collected from students to establish a pre-MET benchmark for motivation, competency, and engagement. This will be done through a combination of surveys and assessments, ensuring a comprehensive understanding of student attitudes, knowledge retention, and technical proficiency prior to MET exposure.

To measure student motivation and engagement levels before MET integration, this study will use the Student Motivation Scale [9], which has been adapted into a Pre-METs Questionnaire Survey. This instrument consists of Likert-scale questions (1-7, Strongly Disagree to Strongly Agree) that evaluate the following:

- ***Self-Belief:*** A student's confidence in their ability to succeed in embedded systems coursework.
- ***Learning Focus:*** Whether students seek to understand embedded concepts or just complete assignments for the marks.
- ***Persistence:*** The extent to which students continue working through challenges.
- ***Avoidance Behaviors:*** Whether students procrastinate or avoid difficult coursework.
- ***Anxiety and Control Perceptions:*** Student concerns about exams and whether they feel in control of their learning outcomes.

This survey will be administered at the start of the semester, before students engage with MET-based learning. The responses will be analyzed to identify motivation trends and determine potential correlations with later academic performance. To establish a pre-MET benchmark for student competency in embedded systems, an additional assessment tool will be administered to evaluate students' baseline knowledge retention and problem-solving ability. A standardized pre-assessment will cover fundamental embedded systems topics, including microcontrollers, logic design, and real-time processing, measuring students' ability to recall theoretical concepts and their understanding of digital logic, analog interfacing, and embedded programming.

Alongside this, students will complete an assignment involving basic embedded programming tasks, which will later be referenced in the post-questionnaire interview. This assignment serves as a self-assessment opportunity, allowing students to reflect on their approach to coding, debugging, and problem-solving. During the post-course evaluation, students will discuss how independently they developed their code, whether they relied on reference materials or external help, and what specific challenges they encountered while completing the task. This reflection-based approach ensures that insights into programming competency are captured qualitatively, focusing on students' learning experiences rather than direct performance comparisons.

After MET-Based Learning Implementation

Following MET-based learning, students will be re-evaluated to measure changes in motivation, competency, and engagement. This post-assessment phase consists of surveys, project evaluations, and qualitative interviews, ensuring that both quantitative and qualitative insights are captured. To assess changes in motivation, students will complete a Post-METs Questionnaire Survey, which mirrors the Pre-METs Questionnaire and follows the Student Motivation Scale [9]. By comparing pre- and post-survey responses, this study will determine whether exposure to MET-based learning had a measurable impact on self-belief, persistence, and engagement levels.

Student competency will be reassessed through a post-course standardized assessment covering fundamental embedded systems topics. This assessment will mirror the pre-assessment administered at the start of the semester, allowing for a direct comparison of knowledge retention and conceptual understanding between students who participated in MET-based learning and those who followed traditional coursework. In addition to the structured assessment, students will reflect on their programming competency and independent problem-solving ability. During the Post-Questionnaire Interview, students will discuss their experiences with MET-based learning, particularly regarding how independently they developed their code, what challenges they faced, and whether MET modules influenced their approach to problem-solving. Students will also be asked to assess the relevance of prior coursework to their embedded systems projects, identifying which foundational courses contributed to their ability to complete MET-related assignments. This assessment will highlight whether students who participated in MET-based learning demonstrate stronger embedded systems proficiency compared to those who followed traditional coursework.

To **determine the effectiveness of MET-based learning, statistical techniques will be used to analyze numerical data** from motivation surveys, knowledge assessments, and project evaluations. A **one-way ANOVA will be conducted to evaluate differences** between the control group (traditional coursework) and the experimental group (MET-based learning). The Student

Motivation Scale **survey results will be statistically analyzed to determine changes in motivation factors** such as self-belief, persistence, and anxiety. Comparisons will be made between pre- and post-surveys, as well as between the control and experimental groups, to assess whether MET-based learning had a measurable impact on student engagement. **Further analysis will be conducted using regression models to explore correlations** between student motivation, assessment performance, and project success, allowing for an examination of whether students with higher motivation scores performed better in embedded systems coursework, particularly in MET-based projects.

To **complement the statistical results, qualitative data from student reflections, interviews, and faculty feedback will be analyzed** to gain deeper insight into student experiences, challenges, and perceptions of MET-based learning. **Open-ended responses** from the Post-Questionnaire Interview will be **categorized into themes using a qualitative coding approach**. Recurring topics such as perceived project difficulty, learning barriers, and MET effectiveness in improving problem-solving skills will be identified to assess how students experienced the MET-based approach. Faculty members will provide feedback on the feasibility of integrating METs into embedded systems courses, the challenges of curriculum adaptation, and the perceived impact of MET-based learning on student outcomes. This input will inform recommendations for long-term MET adoption.

Preliminary Findings

The preliminary findings of this study are based on two phases of research. The first phase, detailed in [2], assessed student engagement, motivation, and subject competency before the introduction of METs. This pre-MET study established a baseline dataset, serving as a reference point for evaluating the impact of MET-based learning in later phases. The findings from this phase highlighted several key challenges in traditional embedded systems education, particularly in terms of student confidence, motivation, and interdisciplinary connections.

The second phase, documented in [17], introduced MET-based learning into selected courses and measured its effectiveness through student performance metrics, motivation surveys, and project evaluations. This phase utilized quantitative comparisons of pre- and post-assessments, revealing statistically significant improvements in student knowledge retention and motivation. In particular, students using MET modules demonstrated enhanced conceptual understanding of embedded systems, digital logic, and analog interfacing, as reflected in their post-assessment scores. The study also examined project performance metrics, showing that students in MET-based learning environments produced more complex and efficient embedded systems projects compared to those in traditional courses. These findings provided empirical evidence supporting the integration of MET-based learning in embedded systems education.

Publication 1: Establishing Baseline Data on Student Success in Embedded Systems Education

Published in the IEEE Frontiers In Education Conference in 2022, this work in progress paper reported on research aiming to measure student success in embedded systems prior to implementation of MET-Based learning. As an ABET accredited university, the Electrical and Computer Engineering program at the University of New Haven is a great representation of a typical curriculum and an accessible university for the initial case study. Table 2 lists the courses within the ECE curriculum and details their link to embedded systems.

Table 2: 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

The **key framework in this publication is Motivation Theory** using Martin's Student Motivation Scale [9]. A 7-point Likert scale was used to allow students to self-assess how well they agree or disagree with the series of questions outlined in the framework. Additionally, a structured assessment is administered to determine the participants level of connections and ability to solve problems. This assessment also uses a 7-point Likert scale and was asked to students at the junior or senior level whom have completed the majority of courses listed in Table 2. Further details are outlined in [3].

Participants for this study were recruited from current and former students of the course titled Embedded Systems: Microcontrollers. In total, fifteen individuals volunteered to participate in the surveys and interviews. Table 3 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 3: Motivation 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 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

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.

Limitations are highlighted in [3], including the lower quantity of datapoints and that the testing method relies on self-reports for determining motivation. Per Martin, the ideal scenario for the Student Motivation Scale has maximized boosters and minimized guzzlers. Data from the p**re-interview survey results** in Table 3 indicate a **strong level of booster thoughts**, but **lower booster behaviors**.

- **Self-Belief (92.4%)**: Indicates that most students feel confident in their ability to complete assignments.
- **Value of Schooling (88.6%)**: Suggests participants recognize the relevance of assignments to real-world challenges.
- **Learning Focus (96.3%)**: Shows students are willing to concentrate on solving stimulating problems.
- **Planning/Monitoring (73.3%)**: A lower score suggests students struggle with clarity in planning and overseeing their work.
- **Persistence (77.1%)**: Indicates a lack of motivation to persevere through challenging or difficult assignments.
- **Guzzler Thoughts and Behaviors**: The pre-survey also revealed elevated scores in these areas.
- **Anxiety (73.3%)**: Reflects worry or fear about underperforming on assignments.
- **Low Control (44.8%)**: A lower score here suggests students have some sense of what needs to be done, but still lack complete clarity or support.
- **Avoidance (76.2%)**: Implies that students are driven more by fear of poor grades than by genuine interest in the subject matter.
- **Self-Sabotage (73.3%)**: Highlights that students are not prioritizing the completion of assignments, which reduces their likelihood 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.

The post-interview data in Table 4 indicates a weak connection between embedded topics taught in classes and the embedded systems course.

- **Strongest Connections**:
  - I. **CSCI1110 (74.3%)**: Covers the programming language used by embedded microcontrollers.
  - II. **ELEC4497 (78.6%)**: Senior design experience where embedded systems are often implemented.
  - III. **ELEC3397 (81.3%)**: Junior design experience that frequently uses embedded systems.
- **Lowest Connections**:
  - I. **EASC1107 (20.9%)**: Provides a first introduction to embedded systems.
  - II. **EASC2230 (33.3%)**: Offers an overview of signals and sensors commonly employed 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.

Expanding On the Publication Results

An important question to consider is why some courses consistently yield higher student performance while others struggle, as shown in Table 4. By examining curriculum structures and analyzing data from multiple courses, we identified clear disparities in student outcomes, reinforcing the need to investigate which factors contribute to high-performing courses and, more importantly, to understand the challenges faced by low-performing courses to determine where improvements can be made.

To further explore these disparities, we conducted a series of student interviews to establish baseline data on student ability, engagement, and understanding of embedded topics throughout the curriculum. Responses were measured using a 7-point Likert scale, where lower average scores support our hypothesis that students in certain courses struggle with embedded systems concepts.

To statistically validate these findings, a single-factor analysis of variance (ANOVA) was conducted as shown in Table 5. The results showed that *F* exceeded *F-critical*, indicating a significant effect. Furthermore, the p-value was significantly lower than the standard alpha threshold (0.05), leading us to conclude that the differences in student performance between courses are statistically significant and not due to random chance.

Table 5: Analysis of Variance on Table 4 Results.

Course Code	***Count***	***Average***	***Variance***
Independent Coding	14	4.60	1.60
EASC1107	13	1.46	0.44
CSCI1110	15	5.20	3.03
ELEC1155	15	3.60	2.83
EASC2230	15	2.33	2.24
ELEC2247	14	2.75	2.80
ELEC2255	13	4.35	3.39
ELEC3397	13	5.69	2.56
ELEC4452	5	2.40	2.80
ELEC4498	9	5.50	3.50

F	***P-value***	***F crit***
11.4	2.01E-11	2.0

Since ANOVA does not identify *what* the differences are, we further analyzed the data by comparing theoretical courses to project-based courses. Table 6 shows the results of our single-factor ANOVA comparing the results of student performance in hands-on project-based courses against traditional theoretical courses. While the overall scores were lower than desired, courses that incorporated hands-on, project-based learning yielded significantly higher average scores compared to those that followed a traditional lecture-based approach. Since *F* is greater than *F-critical*, we conclude the test is significant and, since the *P-value* is significantly less than the standard alpha value (0.05), we conclude the difference between the dataset answers is not by random chance, but rather by the nature of instruction, whether project-based or theoretical, has a measurable impact on student performance in embedded systems education.

Table 6: Analysis of Variance comparing the results from courses taught with a hands-on approach and a theoretical approach.

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

F	*P-value*	*F crit*
66.09	7.05E-13	3.93

With a rating of 69% for hands-on courses and 26% for theoretical, **we validate our hypothesis that the current projects within the curriculum do not sufficiently engage students, educate on embedded topics, nor inspire curiosity for independent learning.** 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. Our solution is to develop modular embedded tools (METs) as a project-based approach of addressing the challenges encountered when teaching embedded systems within the curriculum.

Publication 2: Preliminary Results of Modular Embedded Tool Implementation

Published in the IEEE Frontiers In Education Conference in 2023, this work in progress paper reported on research aiming to measure student success in embedded systems after implementation of MET-Based learning in three courses at the University of New Haven.

This publication focuses on the **repeated implementation of the motivation theory** framework, and the **addition of a new project-based learning** framework. Two modules, MET1155 and MET2230, were developed and implemented within three courses listed in Table 1, ELEC1155, EASC2230, and ELEC3371. These modules follow the core principles of hands-on problem solving, collaborative learning, and integration of theory and practice. These new projects were integrated into the mentioned course lesson plans, then the results measured by the same methods used in the first publication. Details on these methods are found in [17].

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.

Table 6 details the data summary and analysis of variance comparing the baseline data from [3] 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 the connection to embedded systems.
- A **single-factor ANOVA** returned a **p-value of 3.79E-04**, indicating that the difference between the datasets supports the hypothesis by demonstrating a near-zero probability of these results occurring by random chance.

Table 7: 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

Table 7 shows the data summary and analysis of variance comparing the baseline data in [3] with the population which utilized the MET2230 device.

- Participants who used MET2230 scored **166% higher** than baseline participants in their knowledge level and connection to embedded systems.
- A **single-factor ANOVA** yielded a **p-value of 6.80E-06**, indicating that the difference between the datasets supports the hypothesis by showing a near-zero probability of these results occurring by random chance.

Table 8: 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

Table 8 shows the results comparing the population which utilized the implemented modules with the baseline data gathered in [3].

- Booster thoughts for self-belief and learning focus did not significantly increase or decrease.
- 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 9: 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%

As shown in Table 6 and Table 7, 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 8 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 6 and 7.

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].

Expected Outcomes and Contributions

This study aims to demonstrate the effectiveness of MET-based learning in embedded systems education by measuring its impact on student motivation, knowledge retention, interdisciplinary connections, and independent problem-solving skills. Through a structured, research-driven implementation, METs are expected to provide a scalable, hands-on instructional model that enhances engagement, technical competency, and curriculum integration.

The primary expected outcome of this study is that students who engage with MET-based learning will show statistically significant improvements in embedded systems competency compared to those in traditional coursework. This includes higher post-assessment scores in digital logic, microcontroller programming, and analog circuit design, as well as an increase in self-reported confidence in problem-solving and coding independence. The study also expects to find a correlation between motivation scores and student performance, reinforcing the role of project-based learning and hands-on education in improving student engagement and outcomes.

Beyond student outcomes, this research is expected to contribute to the broader field of embedded systems education by providing a validated instructional model that can be adapted to ABET-accredited engineering programs. By aligning with Motivation Theory, PBL, and TPACK, METs offer an approach that can be replicated and scaled across multiple institutions. This study also seeks to contribute to faculty development, equipping educators with modular, hands-on teaching tools that improve curriculum delivery and student engagement in embedded systems courses.

In addition to immediate student learning benefits, MET-based learning is expected to have long-term impacts on embedded systems education. Students who participate in MET-integrated coursework will be more likely to apply embedded systems concepts in real-world projects, senior design capstones, and industry internships. Additionally, METs may serve as a foundation for future educational research, enabling further exploration of modular hardware-based learning models, interdisciplinary engineering education, and adaptive pedagogical strategies.

By demonstrating the effectiveness of MET-based learning, this research will provide empirical evidence for the benefits of hands-on, structured, and modular instructional tools. These findings will support curriculum redesign efforts in embedded systems programs and encourage the adoption of active learning methodologies in engineering education.

Research Timeline and Milestones

Research will be conducted in three major phases

1. Phase 1 – Baseline Data Collection and Initial MET Integration **(Completed)**
    I. Conduct Pre-MET assessments on motivation, knowledge retention, programming.
    II. Establish baseline dataset for traditional embedded systems courses.
    III. Develop and refine MET learning modules.
    IV. Implement pilot MET integration in select courses.
2. Phase 2 – Full MET Implementation and Data Collection **(Ongoing)**
    I. Expand MET integration into multiple courses.
    II. Diversify the participant population by integration at one or more additional universities.
    III. Conduct assessments and analyze performance metrics compared to baseline.
3. Phase 3- Data Analysis, Refinements, and Final Dissertation Preparation **(Future)**
    I. Perform statistical analysis (ANOVA, correlation studies, etc) on pre and post MET-based learning.
    II. Conduct qualitative coding of student and faculty interviews to assess MET impact.
    III. Finalize research conclusions and document methods for MET curriculum adoption.
    IV. Prepare and submit dissertation and journal publications based on research findings.

Projected Milestones

Milestone	Expected Completion
Literature and Curriculum Review	Spring 2021
Phase 1 Data Collection Planning	Fall 2021
Completion of Pre-MET Data Collection	Spring 2022
First Publication, IEEE Frontiers in Education	Fall 2022
Qualifying Exam	Fall 2022
Develop Modules MET1155, MET2230	Fall 2022
Completion of Pilot MET Data Collection	Spring 2023
Graduate Student Showcase	Spring 2023
Second Publication, IEEE Frontiers in Education	Fall 2023
Phase 2 Data Collection Planning	Spring 2024
Module Refinement Based on Initial Feedback	Fall 2024
ASEE North East Poster Conference	Spring 2025
Proposal Defense	Spring 2025
Integration At Another University	Fall 2025
Phase 3 Data Analysis and Interpretation	Spring 2026
Third Publication, ASEE Journal of Engineering	Fall 2026
First Draft of Dissertation	Fall 2026

Conclusion

This study seeks to modernize embedded systems education by introducing Modular Embedded Tools (METs) as a structured, hands-on approach that bridges the gap between theoretical coursework and real-world engineering applications. Traditional embedded systems education has struggled with student motivation, problem-solving, and difficulties in applying theoretical knowledge to practical challenges. Through the integration of Motivation Theory, Project-Based Learning (PBL), and the Technological Pedagogical Content Knowledge (TPACK) frameworks, MET-based learning provides a scalable instructional model designed to enhance student motivation, interdisciplinary understanding, and technical competency.

The **preliminary findings** from this research demonstrate that **MET-based learning significantly improves student engagement, knowledge retention, and problem-solving skills** compared to traditional coursework. Baseline data collected before MET implementation **highlighted key deficiencies** in traditional embedded systems education, including low student confidence, poor retention of knowledge between courses, and a disconnect between embedded coursework and industry expectations.

Post-MET assessments showed statistically significant improvements in student competency, reinforcing the effectiveness of structured, hands-on learning modules. The comparison between pre- and post-implementation results not only validates MET effectiveness but also provides a roadmap for future curriculum improvements in embedded systems education.

Beyond immediate student learning outcomes, this research makes a broader contribution to engineering education. METs offer an adaptable, scalable approach that can be integrated into ABET-accredited programs, ensuring that students graduate with practical, industry-relevant experience in embedded systems design. Additionally, this research provides faculty with structured instructional tools, equipping educators with the resources needed to transition from lecture-based instruction to a project-driven curriculum.

Looking ahead, this study sets the foundation for continued research into modular, hardware-based learning methodologies. **Future work will focus on scaling METs to additional courses, refining project-based learning strategies, and expanding the integration of MET-based learning into interdisciplinary applications.** By demonstrating the effectiveness of structured, hands-on embedded systems education, this research paves the way for a new era of engineering instruction—one that prioritizes student engagement, real-world application, and adaptive learning methodologies to prepare the next generation of embedded systems engineers.

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