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Enhancing Embedded Systems Competency Through Curriculum-Level Implementation of METs

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Abstract

Traditional embedded systems education often emphasizes theory over practice, resulting in gaps in student engagement, long-term competency, and the ability to apply knowledge across the curriculum. This study investigates the curriculum-level implementation of Modular Embedded Tools (METs), a project-based instructional framework guided by Motivation Theory, Project-Based Learning (PBL), and Technological Pedagogical Content Knowledge (TPACK). Building on prior course-level studies, this work examines outcomes from senior-level engineering students who experienced MET-based instruction throughout their undergraduate program.

Results indicate significant improvements in both motivational boosters (e.g., self-belief, persistence, and learning focus) and reductions in motivational guzzlers (avoidance and self-sabotage) when compared to baseline data from traditional coursework. Competency scores in digital systems, analog circuits, and embedded programming increased by approximately 120% relative to baseline performance, confirming that MET-based learning fosters deeper knowledge retention and independent problem-solving ability. Senior-level outcomes also closely mirrored the gains observed in earlier course-level implementations, demonstrating strong knowledge retention across academic years.

These findings suggest that MET-based learning not only enhances immediate course outcomes but also supports enhanced competency throughout the engineering curriculum. This work contributes an instructional model that bridges theory and practice, strengthens student motivation, and prepares graduates with the embedded systems skills demanded by industry.

Introduction

Embedded systems education plays a critical role in preparing electrical and computer engineering graduates for careers in industries such as consumer electronics, automotive systems, industrial automation, and medical device manufacturing. These systems demand engineers who can integrate digital logic, analog circuits, signal processing, and embedded software into reliable, real-world solutions. Despite this need, prior research has shown that traditional embedded systems curricula often emphasize theoretical methods over hands-on approaches, resulting in gaps in student motivation, knowledge retention, and the ability to transfer learning across courses [1].

Recent work has demonstrated that these gaps are not isolated to individual courses, but instead are systemic across embedded systems curricula. In an initial baseline study, junior- and senior-level students reported strong self-belief and general interest in engineering, yet demonstrated weak connections between foundational courses and embedded systems applications, limited independent coding ability, and elevated motivational “guzzlers” such as avoidance and anxiety [1]. Subsequent work introducing Modular Embedded Tools (METs) at the course level showed statistically significant improvements in both student competency and motivation when hands-on, project-based modules were embedded within individual courses [2].

While these findings validated METs as an effective course-level instructional intervention, an open and critical question remains: do these gains persist when METs are implemented systematically across multiple courses throughout the curriculum? Engineering education literature frequently reports short-term improvements tied to isolated pedagogical innovations; however, fewer studies examine whether repeated, scaffolded exposure leads to durable competency and sustained motivation by the time students reach the senior year. This study addresses that gap by examining the curriculum-level implementation of METs across multiple embedded-systems-related courses within an undergraduate electrical and computer engineering curriculum.

Rather than focusing on a single course or semester, this work evaluates senior-level outcomes after students have encountered MET-based learning multiple times throughout their undergraduate experience. Data were collected through semi-structured interviews and motivation surveys administered to graduating seniors across two academic years, including students who completed the curriculum both before and after MET integration.

Student motivation is examined using Martin's Motivation Theory framework, which distinguishes between motivational boosters (e.g., self-belief, learning focus, persistence) and motivational guzzlers (e.g., anxiety, avoidance, self-sabotage). While prior studies showed that MET-based learning increased booster behaviors and reduced guzzler behaviors at the course level [2], this work investigates whether those trends are sustained when METs are integrated across the curriculum. Student technical competency is evaluated through comparative analysis of senior interview assessments relative to baseline cohorts described in earlier work [1], with a focus on retained knowledge in digital and analog systems and integration with embedded systems.

This paper seeks to examine whether repeated exposure to MET modules across multiple courses is associated with improved embedded systems competency by the senior year relative to baseline cohorts educated under a traditional curriculum. It also evaluates how sustained, project-based engagement influences student motivation over time. In contrast to prior work that evaluated METs at the course level [2], this study investigates whether earlier gains persist when METs are implemented as a coherent, curriculum-level instructional strategy. By focusing on senior outcomes following longitudinal exposure to MET-based learning, this paper aims to provide insight into how modular, reusable hardware-based learning tools may support curriculum coherence, long-term knowledge retention, and student motivation in embedded systems education.

Background & Frameworks

A. Framework 1: Motivation Theory

Student motivation is a critical factor influencing engagement, persistence, and achievement in engineering education. Motivation plays a central role in both course performance and willingness to persist through challenging material [3]. To examine motivation in this study, the framework developed by A.J. Martin is used, which breaks down motivation into factors that enhance motivation ("boosters") and factors that detract from motivation ("guzzlers"). Rather than treating motivation as a single construct, the framework distinguishes between adaptive motivational dimensions such as self-belief, learning focus, value of schooling, planning and monitoring, and persistence, and maladaptive dimensions such as anxiety, low control, failure avoidance, and self-sabotage [4]. This separation provides a practical way to evaluate whether students are motivated and how their motivation manifests in behaviors that either support or detract from learning.

The model indicates that effective educational strategies should seek to maximize motivational boosters while minimizing motivational guzzlers. Martin notes that students may simultaneously exhibit high levels of both boosters and guzzlers. For example, strong self-belief alongside elevated anxiety, suggesting that motivation is not inherently stable or uniformly adaptive across contexts. This distinction is particularly relevant in engineering education, where challenging, high-stakes coursework may elevate anxiety even as engagement and persistence increase.

Prior work applying this framework within embedded systems education has shown that traditional, theory-heavy curricula tend to produce students with relatively strong motivational beliefs but weaker motivational behaviors, coupled with elevated guzzler behaviors such as avoidance and self-sabotage [1]. Course-level implementation of Modular Embedded Tools were associated with increases in booster behaviors such as planning, monitoring, and persistence, as well as reductions in guzzler behaviors, with slight increases in anxiety consistent with higher perceived task stakes [2]. These findings align with Martin's assertion that anxiety, while classified as a guzzler, may coexist with adaptive motivational behaviors in challenging learning environments.

In this study, Motivation Theory serves as a framework for examining whether these motivational effects persist when MET-based instruction is implemented across multiple courses. By focusing on senior-level students who have encountered MET modules repeatedly throughout their undergraduate curriculum, this work investigates whether sustained exposure influences not only immediate engagement but also long-term motivational patterns. In particular, the framework enables analysis of whether curriculum-level integration supports increases in motivational behaviors while mitigating detracting behaviors that can hinder knowledge retention and independent problem solving over time.

B. Framework 2: Project Based Learning

One of the most effective ways to reinforce motivation and engagement in engineering education is through Project-Based Learning (PBL) [6], 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. By engaging students in authentic tasks with tangible outcomes, PBL has been shown to increase student ownership of learning, persistence, and the perceived relevance of coursework.

From a motivational perspective, PBL aligns closely with key constructs identified in Martin's Motivation Theory [4]. Project-based environments support motivational boosters such as learning focus, persistence, and planning and monitoring by requiring students to manage open-ended tasks over extended periods of time. At the same time, PBL has been associated with increased student engagement and intrinsic motivation by providing autonomy and meaningful context for learning [5], [6]. These characteristics are particularly important in embedded systems education, where students must integrate concepts from digital systems, analog circuits, and embedded programming in order to solve realistic design problems.

Research in engineering education has consistently demonstrated that PBL can improve students' ability to apply theoretical knowledge, develop problem-solving skills, and retain information over time [5], [7]. One of the key takeaways from Craik and Lockhart's research on memory retention is that students are more likely to retain information when they can actively relate new knowledge to prior experiences [7]. This finding reinforces the importance of repeated, hands-on exposure to embedded systems concepts throughout an engineering curriculum. Learning experiences that require students to revisit and build upon earlier knowledge promote deeper levels of processing, which are associated with improved long-term retention and transfer.

MET-based learning addresses this need by integrating structured, hands-on projects across multiple courses, reinforcing memory retention through repetition, physical interaction, and real-world context. The MET system applies PBL principles through the use of a modular hardware platform that allows students to interact directly with embedded systems while engaging in structured projects that reuse similar hardware across courses. As students progress through the curriculum, project complexity increases incrementally, reinforcing previously learned concepts while introducing new technical challenges. These projects emphasize real-world applications and require students to develop independent problem-solving skills, supporting both cognitive and motivational development.

Despite the documented benefits of PBL, prior studies also highlight limitations when project-based experiences are implemented as isolated or poorly scaffolded interventions. Students may experience uncertainty, cognitive overload, or frustration when projects lack sufficient structure or are weakly connected to supporting coursework [10]. These challenges suggest that PBL is most effective when implemented as part of a coherent curricular strategy rather than as a single-course intervention. Repeated exposure to project-based experiences, combined with progressive increases in technical complexity and consistent instructional scaffolding, can help students recognize conceptual continuity across courses and strengthen their ability to transfer knowledge.

In this work, Project-Based Learning (PBL) serves as a foundational instructional framework for the curriculum-level implementation of Modular Embedded Tools (METs). By reinforcing project-based learning experiences throughout multiple courses, this approach seeks to strengthen motivational boosters, support deeper learning and knowledge retention, and address known limitations of isolated PBL implementations in embedded systems education. Repeated use of MET-based projects allows students to revisit familiar hardware platforms and design challenges while incrementally deepening their technical understanding, thereby sustaining engagement and reinforcing learning continuity across the curriculum.

C. Framework 3: Technological Pedagogical Content Knowledge

Effective project-based learning in embedded systems education requires the seamless integration of technology into instruction. Mishra and Koehler argue that merely introducing technology into the classroom is insufficient; instead, educators must develop a deep understanding of how technology interacts with both pedagogy and content to create effective and meaningful learning experiences [8]. This perspective aligns with prior studies that highlight limitations in project-based learning when projects are implemented as isolated activities without sufficient scaffolding or alignment with supporting coursework [10].

The Technological Pedagogical Content Knowledge (TPACK) framework provides a structured approach to achieving this integration by emphasizing the interdependent relationship among content, pedagogy, and technology. The framework 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 [9].

Traditional instructional models often treat technology as an isolated component, introduced without sufficient consideration of its impact on pedagogy or content delivery. In contrast, TPACK recognizes that technology is not merely an instructional supplement, but a core component of how knowledge is represented, applied, and learned. Different technologies afford different instructional possibilities, influencing student engagement, knowledge retention, and overall learning experiences. As technology continues to evolve rapidly, educators must develop adaptive strategies that ensure students gain meaningful, hands-on experience with modern tools aligned to learning objectives and industry expectations [9].

In the context of embedded systems education, CK, PK, and TK must be carefully aligned to create a cohesive and effective learning experience. CK represents the foundational concepts of embedded systems, including microcontrollers, digital logic, analog circuits, and hardware–software interfacing. PK refers to instructional strategies that best support student learning in this domain, such as project-based learning, hands-on experimentation, and iterative problem solving. TK encompasses the technological tools and platforms used in embedded systems education, including development boards, programming environments, and debugging tools that enable students to engage with industry-relevant systems.

The Modular Embedded Tools (METs) framework applies TPACK principles by intentionally integrating all three knowledge domains. MET modules reinforce CK by incorporating circuit design and embedded programming activities aligned with core embedded systems concepts. Each module includes structured projects, instructional materials, and assessments grounded in project-based learning, ensuring PK is consistently applied. TK is addressed through the deliberate selection and reuse of hardware platforms, development tools, and real-world engineering applications that support curricular objectives. By aligning CK, PK, and TK, MET-based learning functions not merely as an application of educational technology, but as a structured pedagogical framework designed to enhance student understanding, improve engagement, and support curriculum-level coherence in embedded systems education.

D. Literature Review

Embedded systems education presents unique pedagogical challenges due to its inherently interdisciplinary nature and the cumulative knowledge required for student success. Effective embedded systems instruction requires students to integrate concepts from digital logic, analog circuits, microcontrollers, sensing, and embedded programming while developing the ability to apply these concepts in real-world contexts. Prior studies have consistently identified a disconnect between theoretical instruction and practical application in embedded systems curricula, often resulting in limited skill transfer, reduced student confidence, and difficulty synthesizing knowledge across courses [10], [11].

Several studies have reported positive outcomes from hands-on, application-driven instructional approaches in embedded systems education. Course redesign efforts incorporating laboratories, FPGA-based platforms, and project-centered instruction have shown improvements in student engagement and conceptual understanding when compared to traditional lecture-based methods [12], [13], [14]. These studies demonstrate the value of experiential learning and reinforce the role of project-based approaches in addressing the theory–practice gap. However, most such efforts are confined to individual courses or isolated instructional interventions, limiting insight into how these approaches influence long-term learning outcomes across an entire curriculum.

Recent work has begun to explore curriculum-level integration strategies, including spiral curricula and vertically aligned project sequences. Studies implementing spiral or application-based curricula across multiple courses report improvements in student motivation and academic performance, suggesting that repeated exposure to hands-on learning may support deeper understanding and retention [15], [16]. While these studies provide important evidence supporting curriculum integration, their assessments often focus on course-level outcomes or students' initial exposure to the revised curriculum, leaving questions regarding long-term retention and cumulative competency development unanswered.

Long-term knowledge retention remains a persistent challenge in engineering education, particularly in disciplines that rely on progressive skill development. Research on project- and challenge-based learning has demonstrated that experiential, application-driven instruction can lead to improved long-term retention when compared to traditional educational models [18]. Forte-Celaya et al. showed that students who participated in a challenge-based learning semester demonstrated significantly higher retained knowledge at the time of graduation, as measured by an external standardized examination [18]. While these findings support the effectiveness of experiential learning for durable knowledge acquisition, such models often rely on immersive, time-bounded interventions rather than distributed learning experiences embedded throughout a curriculum.

Across the embedded systems education literature, there remains a lack of empirical studies examining the sustained effects of reusable, modular instructional tools implemented across multiple courses. Few studies investigate whether gains observed in project-based or application-driven courses persist into the senior year or translate into improved independent problem-solving ability. Additionally, motivation is often treated as a secondary outcome rather than examined explicitly through a structured theoretical framework. As a result, limited evidence exists connecting curriculum-level instructional design, long-term competency retention, and student motivational behaviors within embedded systems education.

This study addresses these gaps by examining the curriculum-level implementation of Modular Embedded Tools (METs) across multiple embedded systems courses and evaluating senior-level outcomes in both motivation and technical competency. By focusing on students who experienced repeated, scaffolded exposure to MET-based instruction throughout their undergraduate program, this work extends prior research beyond isolated course interventions and immersive single-semester models, providing insight into the long-term impact of modular, project-based learning on embedded systems education.

Methodology

A. Overview of MET Framework

The Modular Embedded Tools (METs) learning modules were developed as hands-on educational tools designed to bridge the gap between theoretical instruction and practical application in embedded systems education. METs are structured around reusable, modular hardware platforms that support project-based learning while enabling continuity of learning experiences across multiple courses within the undergraduate curriculum. Rather than functioning as isolated laboratory exercises, METs are intentionally designed to be revisited and extended as students progress through successive courses, reinforcing previously learned concepts while introducing increasing technical complexity.

The MET framework is grounded in Project-Based Learning (PBL) principles and aligned with the Technological Pedagogical Content Knowledge (TPACK) framework. Each module integrates embedded systems hardware, structured instructional activities, and industry-relevant development tools into cohesive learning experiences. From a pedagogical perspective, MET-based learning emphasizes hands-on experimentation, iterative design, and independent problem solving. From a technological perspective, the consistent use of a modular hardware platform reduces onboarding overhead and cognitive load, allowing students to focus on conceptual understanding and system-level integration rather than repeatedly learning new tools.

To date, two MET modules have been developed and implemented within the electrical and computer engineering curriculum at the University of New Haven: MET1155 and MET2230. These modules target foundational topics in digital systems and analog systems, respectively, and are designed to support reuse across multiple courses. MET1155 focuses on digital logic, hardware programming, and embedded system fundamentals, while MET2230 emphasizes analog circuits, signal conditioning, and analog-to-digital interfacing within embedded systems contexts.

The MET modules have been incorporated into six relevant undergraduate courses through a combination of direct and indirect instructional interventions, as summarized in Table 1. Direct intervention refers to courses in which MET modules are explicitly integrated into course instruction through structured projects, laboratory activities, and assessments. Indirect intervention refers to courses in which students apply knowledge and skills developed through prior MET exposure, particularly in open-ended design environments such as junior design experiences and senior capstone projects.

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
ELEC3365: 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

In early coursework, METs are introduced in foundational courses such as ELEC1155: Digital Systems: Logic Design and EASC2230: Fundamental Applications of Analog Devices, where students engage directly with MET-based projects aligned with core theoretical content. As students advance through the curriculum, these same MET modules are reused in more advanced courses, including ELEC3356: Digital Systems: Hardware Programming and ELEC3371: Embedded Systems Microcontrollers, allowing students to revisit familiar hardware while applying increasingly sophisticated design techniques.

At the curriculum level, METs also support indirect learning interventions in ELEC3397: Junior Design Experience and the ELEC4497/ELEC4498: Senior Design Capstone sequence. In these courses, students are not formally taught new MET content; instead, they draw upon prior MET-based experiences to support independent system design, troubleshooting, and integration.

This approach enables evaluation of long-term knowledge retention and transfer by examining how effectively students apply previously acquired skills in open-ended, industry-aligned design contexts.

By combining modular hardware reuse, progressive scaffolding, and intentional curricular integration, the MET framework operationalizes the principles of PBL and TPACK at the curriculum level. This structure allows METs to function not only as instructional tools within individual courses, but as a cohesive learning system that supports continuity, reinforcement, and long-term competency development across the embedded systems curriculum.

B. Curriculum Integration

This study evaluates curriculum-level outcomes from MET-based learning at the University of New Haven; however, the MET framework is intended to be portable to other programs seeking to improve embedded systems competency through repeated, scaffolded, hands-on exposure. The following replication guide summarizes a practical process for integrating MET-style modules across an undergraduate curriculum.

- Step 1: Identify an anchor embedded systems course.
- Step 2: Map prerequisite and feeder courses that support the anchor course.
- Step 3: Select MET hardware suitable for reuse across courses.
- Step 4: Introduce MET modules in foundational courses before the anchor course.
- Step 5: Reinforce and extend the same MET hardware in the anchor course.
- Step 6: Support indirect intervention through design-sequence courses.
- Step 7: Align learning outcomes across the curriculum.

Begin by selecting an “anchor” course in which embedded systems are central and where students are expected to synthesize knowledge across domains. In many electrical and computer engineering curricula, this is a microcontrollers course, an embedded systems course, or an embedded circuit design course. The anchor course should include substantial hands-on design work and serve as a natural convergence point for digital logic, analog interfacing, and embedded programming skills.

Once the anchor course is selected, identify the foundational courses that directly feed into it. These typically include at least one digital systems course (logic design, HDL, or digital hardware fundamentals) and at least one analog/electronics course (circuits, analog devices, signal conditioning, sensors). The goal is to determine where embedded-relevant concepts are already taught but may not be connected to embedded applications.

Choose a modular hardware platform that can be introduced early and reused across later courses without requiring students to relearn entirely new toolchains each semester. To support curriculum-level continuity, the hardware should (1) scale in complexity, (2) support both introductory and advanced activities, and (3) allow extension through additional peripherals or subsystem “modules.” Reuse is a key design constraint: the platform should remain relevant in the anchor course and beyond.

Integrate MET-based learning first in foundational courses where students are learning core theory for the first time. In these courses, MET activities should function as structured PBL experiences that connect theory to observable system behavior. The purpose is twofold: (1) establish early familiarity with the hardware/software environment, and (2) build conceptual “anchors” students can revisit later. Early modules should emphasize guided practice, clear scaffolding, and frequent feedback to reduce cognitive overload.

In the anchor embedded systems course, reuse the same MET platform introduced earlier, but shift the learning emphasis from guided practice toward integration and independent design. Projects should require students to combine prior concepts (e.g., digital I/O, timing, sensing, analog-to-digital conversion, debugging) in a cohesive system. This step is critical for promoting transfer: students should recognize that earlier MET-based experiences are directly applicable to embedded system design tasks.

To extend learning beyond structured coursework, incorporate MET continuity into junior design experiences and senior capstone projects, even if MET content is not explicitly taught in those courses. These design environments serve as an indirect intervention where students can demonstrate whether prior MET exposure translates into independent problem solving, troubleshooting ability, and system integration skills. This also provides a natural opportunity to assess long-term retention.

Finally, align course-level outcomes so that MET-based experiences develop progressively from foundational competencies to integrated system design. Outcomes should be written to reflect both content progression and tool reuse—for example, moving from “describe and implement basic digital logic” to “integrate digital logic, sensing, and embedded software to meet system requirements.” Alignment should also include consistent expectations for debugging, documentation, and iterative testing, since these behaviors reinforce both competency and motivation.

C. Assessment Method

To evaluate the impact of curriculum-level implementation of METs, this study employs a mixed-methods assessment approach combining competency evaluation, motivation measurement, and performance-based evidence. The assessment strategy is designed to capture both technical proficiency and motivational outcomes among senior-level students who experienced MET-based learning across multiple courses, and to enable comparison with baseline cohorts who completed the curriculum prior to MET integration.

Student technical competency was evaluated through semi-structured interviews conducted with senior-level students during the 2024 and 2025 academic years. The interviews focused on core embedded systems competencies aligned with MET1155 and MET2230 learning objectives, including digital logic, embedded programming, analog interfacing, and system-level integration. Students were asked to explain concepts, describe design approaches, and reason through embedded systems scenarios representative of skills expected at the senior level. Interview responses were scored using a 7-point Likert scale to assess depth of understanding, conceptual accuracy, and the ability to independently reason about embedded systems problems. This approach emphasizes retained knowledge and problem-solving ability rather than short-term recall. Competency scores from students who experienced curriculum-level MET integration were compared with scores from baseline cohorts who completed similar coursework without MET-based learning [1].

Student motivation was assessed using a survey instrument based on Martin's Student Motivation Scale. The survey was administered to senior-level students at the time of interview, allowing for examination of motivational patterns after extended exposure to MET-based learning across the curriculum. Survey results from MET-exposed seniors were compared with baseline motivation data collected in prior work from students educated under a traditional embedded systems curriculum. This comparison enabled evaluation of whether curriculum-level MET implementation was associated with sustained changes in motivational behaviors, rather than short-term course-specific effects.

Quantitative data from competency scores and motivation surveys were analyzed using statistical methods appropriate for group comparison. Differences between MET-exposed seniors and baseline cohorts were evaluated to identify statistically significant changes in both technical competency and motivational factors. These analyses focused on detecting sustained effects attributable to repeated, scaffolded exposure to MET-based learning. Qualitative data from interview responses were analyzed to contextualize quantitative findings and to provide insight into how students perceived their learning experiences, independent problem-solving development, and ability to apply knowledge gained in earlier coursework to open-ended embedded systems tasks.

Results

A. Competency Outcomes

Senior-level competency assessment results indicate a statistically significant and substantial improvement in embedded systems competency among students who experienced curriculum-level implementation of METs when compared to baseline cohorts educated under a traditional curriculum. Competency was evaluated separately for the two MET modules to reflect differences in content focus and curricular placement.

For MET2230-related competencies, students in the MET-exposed senior cohort ($n = 18$) achieved a mean competency score of 5.80 with a variance of 0.60, compared to a mean score of 2.35 with a variance of 1.52 among baseline students ($n = 26$). Statistical analysis revealed a highly significant difference between groups ($F = 110.47$, $p = 2.49 \times 10^{-13}$), exceeding the critical F-value ($F_{crit} = 4.07$). These results indicate a substantial improvement in retained analog and analog-to-embedded systems competency among seniors who encountered MET2230 across multiple courses. MET2230 is first introduced in EASC2230 and later reused in ELEC3371 and ELEC3398, providing repeated exposure to analog interfacing concepts within embedded systems contexts. Table 2 summarizes competency outcomes including group means, variances, and statistical test results. This result indicates that students exposed to MET-based learning demonstrate substantially stronger retained competency in analog and embedded systems concepts, with performance levels more than doubling those students from the traditional curriculum.

Table 2: Analysis of Variance comparing the results from seniors who were taught with a METs approach and a theoretical approach.

Groups	*Count*	*Average*	*Variance*
MET2230 Seniors Avg	18	5.80	0.60
MET2230 Baseline	26	2.35	1.52

F	*P-value*	*F crit*
110.47	2.49E-13	4.07

Similarly, MET1155-related competency outcomes demonstrate significant gains for MET-exposed seniors. Students who experienced curriculum-level MET1155 integration (n = 27) achieved a mean competency score of 6.20 with a variance of 0.33, compared to a mean score of 3.27 with a variance of 2.20 for baseline students (n = 26). The difference between groups was statistically significant ($F = 91.05$, $p = 6.22 \times 10^{-13}$), exceeding the corresponding critical F-value (F_crit = 4.03). MET1155 is introduced in ELEC1155 and subsequently reused in ELEC3371, ELEC3398, and ELEC3365, allowing students to repeatedly apply digital systems and embedded programming concepts using a consistent hardware platform. Table 3 summarizes competency outcomes including group means, variances, and statistical test results. These findings suggest that repeated exposure to MeT1155 across the curriculum leads to markedly improved mastery of digital systems and embedded programming, enabling students to perform at a consistently higher level by the senior year.

Table 3: Analysis of Variance comparing the results from seniors who were taught with a METs approach and a theoretical approach.

Groups	*Count*	*Average*	*Variance*
MET1155 Seniors Avg	27	6.20	0.33
MET1155 Baseline	26	3.27	2.20

F	*P-value*	*F crit*
91.05	6.22E-13	4.03

B. Motivation Outcomes

Motivation outcomes were evaluated by comparing senior-level motivation survey results from students who experienced curriculum-level MET-based learning with baseline motivation data collected prior to MET implementation. Motivation was analyzed using Martin’s framework, which categorizes motivation into booster thoughts and behaviors, and guzzler thoughts and behaviors. Average scores for each category were calculated for both baseline and senior cohorts.

Across all booster categories, seniors who experienced MET-based learning demonstrated higher average motivation scores compared to baseline students. For booster thoughts, average self-belief increased from 88.5% at baseline to 91.7% among seniors, value of schooling increased from 86.8% to 93.6%, and learning focus increased from 90.1% to 94.0%. Booster behaviors also showed increases, with planning and monitoring rising from 70.9% to 79.3%, and persistence increasing from 74.2% to 82.0%.

Changes were also observed in guzzler-related categories. For guzzler thoughts, perceived low control decreased from a baseline average of 49.5% to 45.5% among seniors. In contrast, anxiety increased from 73.1% at baseline to 83.8% among seniors. For guzzler behaviors, avoidance decreased from 74.7% to 65.4%, and self-sabotage decreased from 71.4% to 62.4%. Table 4 summarizes average motivation scores for baseline and senior cohorts across all booster and guzzler dimensions. Overall, these results indicate that curriculum-level MET implementation is associated with more productive motivational patterns, including stronger persistence and reduced avoidance behaviors, which are critical for sustained engagement in complex engineering tasks.

Table 4: Motivation survey results detailing average scores for booster and guzzler thoughts and behaviors.

		AVG Score (Baseline)	AVG Score (Seniors)
Booster Thoughts	Self-Belief	88.5%	91.7%
	Value of Schooling	86.8%	93.6%
	Learning Focus	90.1%	94.0%
Booster Behaviors	Planning/Monitoring	70.9%	79.3%
	Persistence	74.2%	82.0%
Guzzler Thoughts	Anxiety	73.1%	83.8%
	Low Control	49.5%	45.5%
Guzzler Behaviors	Avoidance	74.7%	65.4%
	Self-Sabotage	71.4%	62.4%

Discussion

A. Interpretation of Data

The results of this study indicate that curriculum-level implementation of Modular Embedded Tools (METs) is associated with improved senior-level embedded systems competency and sustained changes in student motivation when compared to baseline cohorts. These findings extend prior course-level MET studies by examining whether instructional benefits observed within individual courses persist when MET-based learning experiences are reinforced across multiple courses throughout the undergraduate curriculum.

One likely contributor to the observed competency gains is the repeated, scaffolded exposure to embedded systems concepts enabled by MET reuse across courses. Prior course-level implementations of MET1155 and MET2230 demonstrated substantial improvements in student competency relative to baseline cohorts when the modules were introduced within individual courses [2]. In the present study, seniors who encountered the same MET modules multiple times across foundational and advanced coursework exhibited similarly elevated competency outcomes, suggesting that repeated engagement with consistent hardware platforms and design tasks may support longer-term knowledge retention and independent problem solving.

Motivation outcomes observed at the senior level also align with patterns reported in earlier MET implementations. Prior work found that MET-based learning was associated with increases in motivational boosters such as planning, monitoring, and persistence, along with reductions in avoidance and self-sabotage behaviors, despite increases in anxiety [2]. In the present study, seniors demonstrated higher average scores across all booster categories and lower scores for several guzzler behaviors when compared to baseline motivation data, while anxiety again increased. This consistency across instructional scales aligns with Motivation Theory, which recognizes that elevated anxiety can coexist with adaptive motivational behaviors in challenging, high-engagement learning environments.

Although the present study focuses on curriculum-level outcomes and prior work examined course-level implementations, the direction and relative magnitude of observed changes in both competency and motivation are consistent across studies [2]. No direct statistical comparison was conducted between datasets; however, the alignment of outcome patterns suggests continuity between course-level and curriculum-level effects. These findings support the interpretation that MET-based learning produces instructional benefits that are not limited to isolated course experiences, but may persist when modules are reused and reinforced throughout the curriculum.

Taken together, the senior-level outcomes reported here, viewed alongside prior course-level MET results [2], suggest that modular, reusable embedded systems tools can support sustained competency development and motivational growth when implemented as part of a coherent, curriculum-level instructional strategy.

B. Limitations

Several limitations should be considered when interpreting the results of this study. First, the study population was limited to students within a single electrical and computer engineering program at the University of New Haven. While this allowed for consistent curriculum implementation and assessment, it may limit the generalizability of the findings to institutions with different program structures, student demographics, or instructional resources.

Second, participation in the senior interviews and motivation surveys was voluntary, introducing the potential for self-selection bias. Students who elected to participate may have had stronger opinions about their educational experiences or higher levels of engagement with embedded systems coursework. As a result, the findings may not fully capture the experiences of all students within the program.

Third, although MET-based learning was integrated across multiple courses, not all students experienced identical levels of exposure. Some students did not enroll in every MET-supported course or may have had variations in instructional delivery due to scheduling, course sequencing, or instructional differences across semesters. Consequently, individual exposure to MET-based learning may have varied, potentially influencing competency and motivation outcomes.

Finally, this study relies on interview-based competency assessment and self-reported motivation measures rather than standardized external assessments. While interviews provide valuable insight into retained knowledge and independent problem-solving ability, they inherently involve subjective judgment despite the use of structured rubrics. Similarly, motivation survey responses reflect students' self-perceptions, which may be influenced by contextual factors at the time of assessment.

With these limitations in mind, the consistency of observed trends across competency and motivation measures, combined with alignment with prior course-level studies, supports the relevance of the results and motivates further investigation through broader, multi-institutional studies.

C. Future Considerations

While the findings of this study support the potential benefits of curriculum-level implementation of Modular Embedded Tools (METs), several opportunities exist to extend and strengthen this line of research. One important area for future work is the expansion of MET-based learning to additional institutions with diverse program structures, student demographics, and instructional resources. Multi-institutional studies would enable evaluation of the generalizability of MET-based approaches beyond a single university context and provide insight into how curriculum design, class size, and institutional constraints influence outcomes.

Future studies may also examine more granular patterns of learning and motivation by analyzing raw competency data and subgroup effects. While the present work focuses on aggregate senior-level outcomes, further analysis could explore how MET-based learning impacts students with varying academic backgrounds, prior preparation, or levels of engagement. Such analyses could inform targeted scaffolding strategies and support more inclusive instructional design.

In addition, longitudinal data collection following individual student cohorts across multiple years could strengthen causal inference regarding knowledge retention and skill transfer. Tracking students from initial exposure to MET modules through senior design experiences would allow direct measurement of learning trajectories and provide deeper insight into how repeated, modular learning experiences influence long-term competency development.

Finally, future work may explore extending the MET framework to additional embedded systems topics or adjacent disciplines, such as controls, communications, or cyber-physical systems. Adapting the modular, reusable tool approach to other domains may further support curriculum coherence and reinforce interdisciplinary connections within engineering education.

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