Integrating Arduino into Experimental-Centric Pedagogy: A Longitudinal Investigation of Motivation and Engagement in Civil and Transportation Engineering

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Dr. Owolabi is also the recipient of the 2020 Morgan State University Outstanding Faculty Award for Excellence in Service. He is an expert in advanced modeling and computational mechanics. His major area of research interests centers majorly in, geotechnical engineering, engineering education, sustainable infrastructure development, computational geomechanics, pavement engineering, Soil mechanics, physical and numerical modeling of soil structures, constitutive modeling, pavement design, characterization and prediction of behavior of pavement materials, linear and non-linear finite element applications in geotechnical engineering, geo-structural systems analysis, structural mechanics and material model development. He is considered to be a paradigm of a modern engineer, possessing a combination of practical experience with the most advanced numerical analysis tools, and knowledge of material constitutive relations - things essential to addressing the challenges of advanced material research and development.

Dr. Owolabi has secured, as PI or Co-PI, about $2.46 million in research grants that solved society problems in transportation engineering, fostered sustainable infrastructure development and enhanced student engagement in the STEM fields. Dr. Owolabi currently is the Principal Investigator of a three-year

$1.75 Million NSF grant that cuts across multiple STEM disciplines at Morgan titled ”Adapting an Experiment-centric Teaching Approach to Increase Student Achievement in Multiple STEM Disciplines”. Dr. Owolabi has authored over 40 publications/presentations in civil engineering and STEM education. He is a professional engineer registered in Maryland. Dr. Owolabi maintains membership in the Committee on Geo-Environmental and Climatic Impacts on Geomaterials (AKG300) of the Transportation Research Board (TRB), where he plays a vital role in facilitating the exchange of transportation research information and results, through; development of research problem statements in transportation; review and recommendation of papers for publication and for TRB Annual meetings.

1. Introduction

Engineering education has increasingly shifted toward instructional approaches that emphasize active participation, contextual learning, and authentic problem solving. Traditional lecture-dominated models, while effective for content transmission, have been widely critiqued for their limited capacity to sustain student motivation and engagement, particularly in applied engineering disciplines [1], [2]. These concerns are especially salient within Engineering programs, where abstract concepts often precede meaningful exposure to real-world systems and experimentation.

Experimental-Centric Pedagogy (ECP) has emerged as a promising instructional model that puts experimentation at the center of how students learn. Instead of treating labs as an add-on, ECP weaves hands-on work through multiple courses so that students repeatedly try out ideas, watch what happens, and adjust their understanding of engineering concepts as they go [3] . Prior studies suggest that ECP can improve conceptual understanding, promote persistence, and foster professional skill development [4]. However, much of the existing literature relies on short-term or cross-sectional evaluations, limiting insights into how student motivation and engagement evolve across repeated exposure to experimental learning environments. Recent work in transportation engineering has shown that an ECP framework grounded in hands-on, real-world infrastructure scenarios can improve both learning and motivational outcomes. In transportation infrastructure courses, an experiment-centric, hands-on pedagogy using ECP led to increased student motivation, improved cognitive understanding, higher learning gains, and better course success rates compared with traditional approaches [5]. In civil engineering, a pre–post study using the Motivated Strategies for Learning Questionnaire (MSLQ) found that a hands-on, experiential pedagogical model enhanced undergraduates' self-efficacy, supporting the argument that civil engineering curricula benefit from student-centered, practice-focused instruction [6].

Within Historically Black Colleges and Universities (HBCUs), these questions carry additional significance. HBCUs play a critical role in broadening participation in engineering and other STEM fields and have developed educational environments and practices that reduce attrition and foster Black students' engagement and success in science [7]. The context of Historically Black Colleges and Universities (HBCUs) makes these findings especially important. HBCUs play a central role in broadening participation in STEM and in supporting students from groups historically underrepresented in engineering. Jackson [8] adapted and validated the MSLQ for STEM courses at an HBCU, showing that motivational beliefs and learning strategies are meaningful constructs in this context and highlighting their relevance to student success. Despite this context, longitudinal empirical studies examining pedagogical innovation in HBCU engineering programs remain scarce.

This study addresses this gap by examining the long-term motivational and engagement outcomes associated with Arduino-based ECP implementation in Civil and Transportation Engineering courses at an HBCU. By tracking students across multiple academic terms, the study seeks to generate robust quantitative evidence on how experimental-centric learning shapes self-regulated learning behaviors and sustained engagement over time, drawing on data from Fall 2021 through Fall 2024.

The study is guided by three research questions:

1. How do civil and transportation engineering students' motivational beliefs (e.g., intrinsic motivation, task value, self-efficacy for learning and performance) change across repeated exposure to Arduino-based ECP at an HBCU?
2. How do students' self-regulated learning behaviors, particularly metacognitive self-regulation and effort regulation, evolve over the same period?
3. How do classroom engagement patterns, as captured by COPUS, reflect the adoption and refinement of experiment-centric instruction across semesters?

2. Literature Review

Experimental-Centric Pedagogy in Engineering Education

In the HBCU Engineering Network (HBCU-EngNet) project, Experimental Centric Pedagogy has been rolled out in several engineering programs as a hands-on, student-focused approach that aims to boost engagement and give students with different learning preferences more flexible ways to participate [3]. Studies have documented improvements in conceptual understanding, design thinking, and student satisfaction when experimentation is integrated throughout coursework rather than isolated add-on laboratory sessions [9],[10].

Owolabi et al., [5] applied an experiment-centric, hands-on instructional approach in transportation infrastructure courses to strengthen student learning. The instructional activities were built around practical experiments involving structural stress and strain in bridge systems, acoustic considerations for noise mitigation, moisture measurement in roadway compaction, and deterioration mechanisms affecting infrastructure performance. Evaluation of learning outcomes for 92 undergraduate students indicated improvements in motivation, conceptual understanding, and overall learning performance, with higher success rates observed relative to conventional lecture-based instruction [5]. These findings suggest that incorporating realistic, experiment-driven activities into transportation engineering education can effectively enhance both student engagement and conceptual comprehension.

In civil engineering, Ige et al., [6] examined a hands-on pedagogical model grounded in experiential learning theory and used a pre–post design with the MSLQ to investigate its impact on civil engineering undergraduates' self-efficacy. The authors describe self-efficacy as a pivotal factor in engineering performance and argue that civil engineering curricula, which often emphasize theory, need more dynamic, practice-oriented experiences that build both competence and confidence [6]. Their study reports that the experiential, hands-on approach enhanced students' self-efficacy and positions hands-on pedagogy as a viable mechanism for improving motivational outcomes in civil engineering.

Despite these promising findings, much of the empirical evidence remains short-term in nature. Longitudinal studies examining how repeated exposure to ECP influences motivation and engagement are limited, particularly within civil and transportation engineering contexts.

Arduino-Based Learning Environments

Arduino platforms have become widely adopted in engineering education due to their affordability, flexibility, and capacity to support rapid prototyping. Arduino-based laboratories have been associated with increased student interest, improved problem-solving skills, and greater perceived relevance of course content [11], [12], [13].

In STEM education, Arduino systems have been widely used in hands-on, project-based activities to help students apply theoretical knowledge in practical, real-world contexts [10]. However, most existing work focuses on describing implementations and bibliometric trends, while detailed empirical studies on long-term motivational and engagement outcomes remain limited.

Motivation and Engagement in Engineering Students

Motivation and engagement are widely recognized as key influences on students' persistence and success in engineering programs [14], [15]. Constructs like intrinsic motivation, self-efficacy, and self-regulated learning have been shown to influence students' cognitive engagement and classroom performance [6], [16].

The Motivated Strategies for Learning Questionnaire (MSLQ) is a widely used, empirically supported instrument for assessing motivational and learning strategy constructs in higher education settings [17].

When combined with observational tools like the Classroom Observation Protocol for Undergraduate STEM (COPUS), researchers can capture both self-reported motivation and observable engagement behaviors [6]; [18].

3. Theoretical Framework

Experiential Learning Theory

Kolb's Experiential Learning Theory explains learning as an ongoing process that grows out of direct experience. According to this framework, students learn by moving through four connected stages: Active Experimentation, Reflective Observation, Concrete Experience, and Abstract Conceptualization [19]. Learning begins when students take part in a concrete experience, such as performing an experiment or working with a physical system. They then reflect on what happened, considering the results and identifying patterns or unexpected outcomes. These reflections help students form abstract ideas and connect what they observed to theories and analytical concepts. Finally, students apply what they have learned by testing their ideas through further experimentation. Although engineering education naturally involves hands-on problem solving, instructional approaches do not always guide students through all stages of this learning cycle in a deliberate way. Figure 1 illustrates Kolb's Learning Cycle and shows how learning develops through repeated movement between experience, reflection, conceptual understanding, and experimentation.

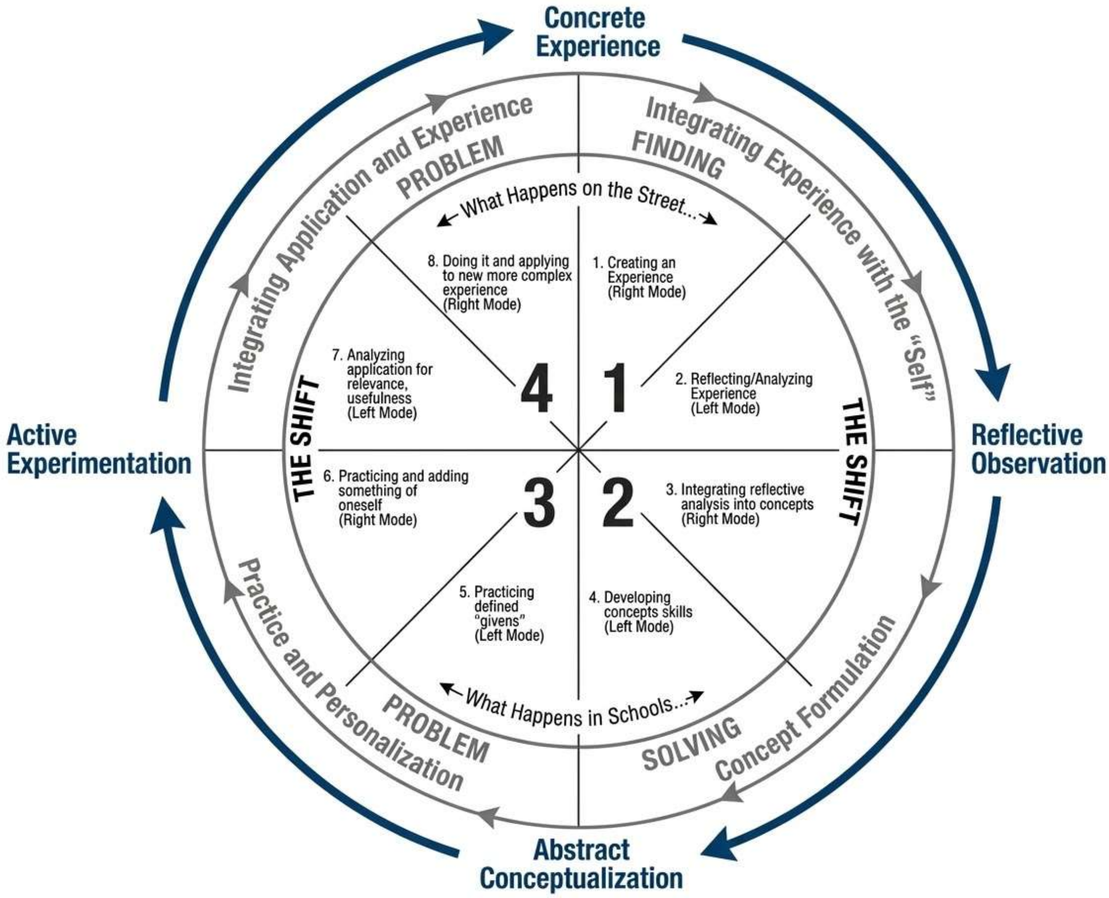

Figure 1: Kolb's Learning Cycle [20]

ECP aligns closely with ELT by embedding experimentation as both a starting point and an outcome of instruction. Arduino-based ECP can be designed to align deliberately with Kolb's cycle. For instance, when students build Arduino-based measurement or control systems and collect data from infrastructure analogues, they engage in concrete experience. When they examine graphs, compare results with predictions, and discuss sources of error, they participate in reflective observation. Connecting observations to governing equations, design specifications, and broader concepts supports abstract conceptualization. Revising code, modifying system parameters, and testing alternative designs constitute active experimentation. Iterating through these stages across multiple experiments and courses is expected to deepen students' conceptual understanding and strengthen their confidence in applying theory in practice [5], [19]).

Furthermore, prior research has shown that experiential learning environments grounded in ELT can enhance conceptual retention and learner autonomy in engineering contexts [21]. Ige et al., [6] explicitly ground their civil engineering hands-on model in experiential learning principles and use self-efficacy as a key outcome, which suggests that experiential frameworks provide a useful lens for designing and interpreting hands-on interventions in engineering. The present study extends this line of work by applying an experiential learning lens to Arduino-based ECP in a civil and transportation engineering program at an HBCU.

Self-Regulated Learning

Self-Regulated Learning (SRL) theory further complements ELT by emphasizing learners' active role in planning, monitoring, and regulating their cognitive and motivational processes [22]; [15]. Within this framework, motivational beliefs such as intrinsic goal orientation, task value, control of learning beliefs, and self-efficacy are not incidental; they influence the amount of effort students invest and how they respond when they encounter difficulties. Self-regulated learning strategies, including metacognitive self-regulation and effort regulation, reflect how students manage their learning processes and sustain their efforts over time [15].

The Motivated Strategies for Learning Questionnaire was developed to measure these constructs in a course-specific way, with separate sections for motivation and learning strategies [15]. The MSLQ includes scales for intrinsic goal orientation, task value, control of learning beliefs, and self-efficacy for learning and performance, as well as scales for metacognitive self-regulation and effort regulation. Jackson [11] adapted and validated the MSLQ for STEM courses at an HBCU, providing evidence that the instrument's factor structure and reliability are acceptable in that context and underscoring the importance of motivation and learning strategies for students at HBCUs.

Ige et al., [6] illustrate how MSLQ-based measures can be used to examine changes in self-efficacy in civil engineering undergraduates exposed to a hands-on, experiential pedagogical model. The present study similarly employs selected MSLQ subscales to investigate how civil and transportation engineering students' motivational beliefs and self-regulated learning behaviors change over time in Arduino-based ECP courses at an HBCU.

Use of Arduino and ADALM2000 in Student Learning

Arduino microcontrollers and the ADALM2000 (Active Learning Module) were used as core instructional tools to support experimental-centric learning across multiple STEM disciplines (see figure 2A). These platforms enabled students to move beyond theoretical instruction by actively engaging in hands-on data collection, real-time measurement, and experimental analysis. Through their use, students were able to design experiments, interface sensors, acquire signals, and interpret physical phenomena using accessible and industry-relevant technology. Also, prior studies consistently had shown that Arduino-based learning environments enhance student engagement, experimental design skills, conceptual understanding, and interdisciplinary problem-solving by enabling low-cost, hands-on interaction with real-world systems and data acquisition [5].

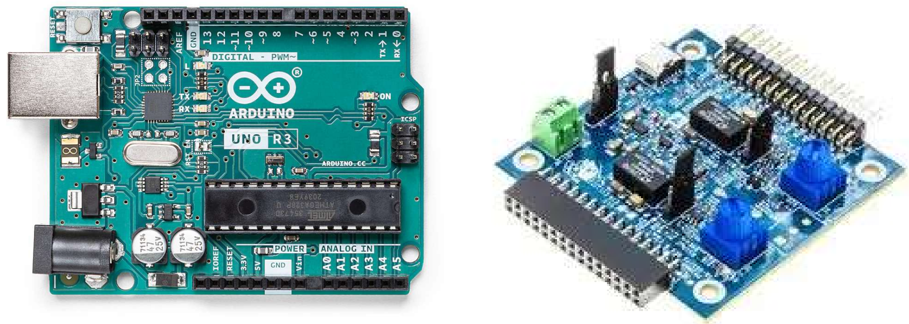

Figure 2A: A typical Arduino Uno and ADALM 2000 (*Courtesy Arduino*)

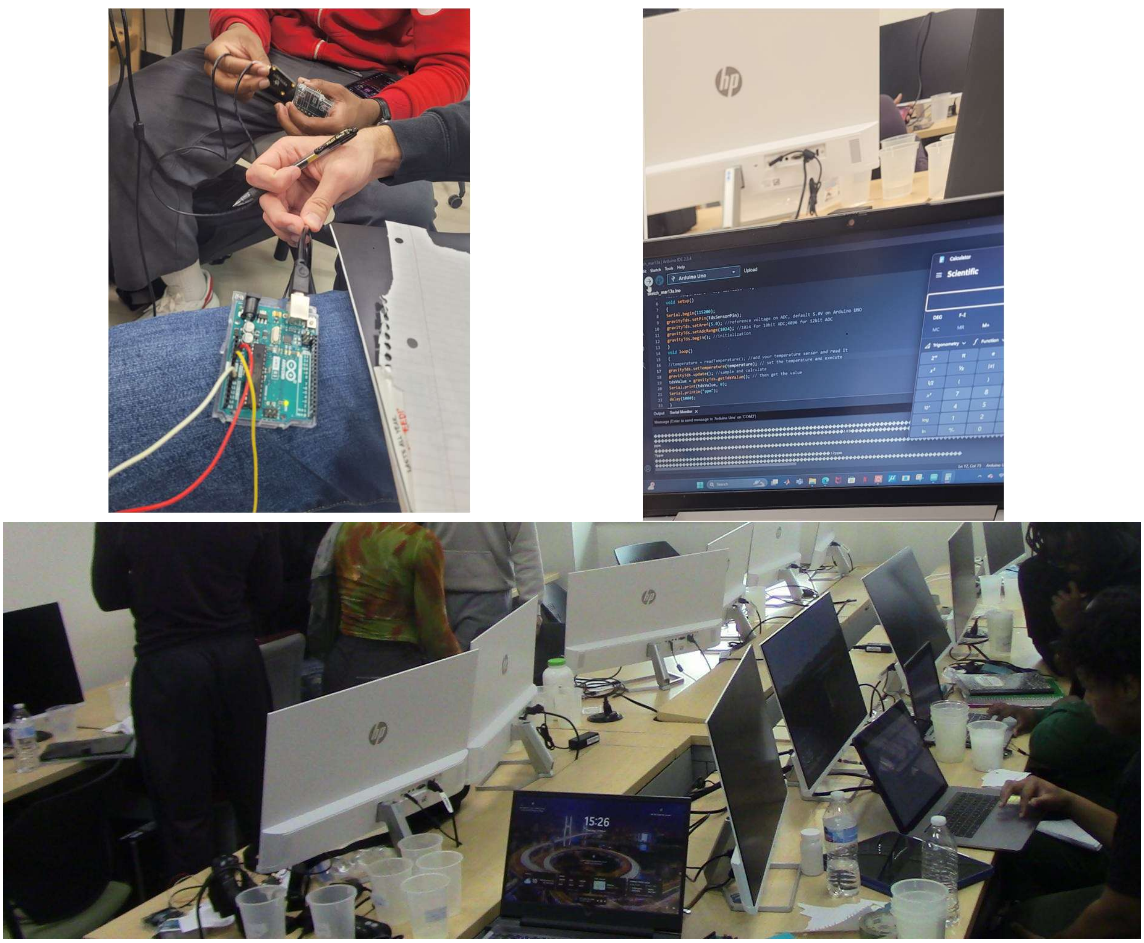

Figure 2B: A classroom engagement using Arduino and other device

The Arduino platform was primarily employed as a flexible data-logging and control system. Students used Arduino boards in laboratory and home-based settings to measure variables such as temperature, humidity, light intensity, dissolved oxygen, pH, strain, vibration, and sound levels. Its compatibility with a wide range of sensors allowed students to explore interdisciplinary applications in biology, chemistry, civil engineering, environmental engineering, physics, and transportation engineering. By programming Arduino to acquire and export data to software such as Microsoft Excel, students developed foundational skills in experimental design, data processing, and quantitative analysis. Figure 2B is a sampled class engagement of the students working with the device.

The ADALM2000 complemented Arduino by providing a multifunctional instrumentation platform that integrates oscilloscope, waveform generator, voltmeter, and logic analyzer capabilities into a single device. Students used the ADALM2000 to visualize real-time signals, examine voltage–strain relationships, study beam deflection and vibration, analyze circuit behavior, and validate theoretical models through direct measurement. Its integration with the ALICE software environment allowed students to immediately connect experimental observations with analytical concepts presented in class

Importantly, both Arduino and ADALM2000 supported flexible instructional delivery. Students were able to conduct experiments in traditional laboratories, hybrid classrooms, and home-based settings without compromising learning outcomes. This flexibility was particularly valuable in promoting equity and access, as students could complete meaningful experiments using portable, low-cost equipment while maintaining consistency with in-person laboratory objectives. It was also easy to use because it supported rapid prototyping, and educational pedagogy. Because it was open source, it was easy for students to contribute to on-going projects, which also encouraged collaboration among students.

In addition to Arduino and ADALM2000, several complementary devices can be added to further enhance student learning through hands-on experimentation and system integration. These include environmental and physical sensors such as temperature, humidity, pressure, light, soil moisture, sound, and pH sensors; mechanics and structural devices such as strain gauges, load cells, accelerometers, gyroscopes, and ultrasonic distance sensors; electrical and electronics tools including breadboards, voltage and current sensors, logic analyzers, and basic circuit component kits; actuators such as servo motors, DC motors, stepper motors, relays, and solenoid valves to introduce control and automation concepts; visualization and interface devices like LCD or OLED displays, LED matrices, keypads, and rotary encoders for real-time feedback; and communication and data-logging modules such as Wi-Fi, Bluetooth, GPS, and SD card modules to support remote monitoring, data storage, and smart infrastructure applications. Together, these devices broaden experimental scope, reinforce theory-to-practice connections, and support interdisciplinary, industry-relevant learning experiences.

4. Methodology

Research Design

This study employs a quantitative longitudinal design to examine changes in student motivation and engagement associated with repeated exposure to Experimental-Centric Pedagogy. Data were collected across multiple academic terms spanning Fall 2021 to Fall 2024, allowing for the examination of trends over time.

Participants and Context

Participants were undergraduate students enrolled in Civil and Transportation Engineering courses at a Historically Black College and University. A total of 170 students were involved in this longitudinal study. The courses incorporated Arduino-based laboratory modules aligned with core disciplinary concepts. Participation in the study was voluntary, and ethical approval was obtained in accordance with institutional research guidelines.

Instructional Intervention

The instructional intervention involved the systematic integration of Arduino-based experimental activities into course instruction. Laboratory modules were designed to align with Kolb's experiential learning cycle, incorporating hands-on experimentation, guided reflection, conceptual modeling, and iterative testing.

Instruments

Student motivation and self-regulated learning strategies were measured using the Motivated Strategies for Learning Questionnaire (MSLQ), focusing on intrinsic motivation, self-efficacy, and effort regulation [6], [16]. Classroom engagement was assessed using the Classroom Observation Protocol for Undergraduate STEM (COPUS), which captures instructor and student behaviors during class sessions [18].

Data Collection Procedures

Survey data were collected at multiple time points across semesters, while COPUS observations were conducted periodically to capture instructional and engagement patterns. Data were anonymized and matched longitudinally using unique participant identifiers.

Data Analysis

Paired-samples t-tests were used to examine pre–post changes in motivational beliefs and self-regulated learning behaviors. Statistical significance was evaluated at $p = 0.05$, and Cohen's d was calculated to assess practical significance. Items on the MSLQ test anxiety subscale were reverse coded so that higher scores indicate lower test anxiety, ensuring consistency in the direction of all metrics.

Descriptive statistics were used to summarize classroom engagement and learning outcome attainment. All statistical analyses were conducted using SPSS Version 27.

5. Results

5.1 Changes in Motivational Beliefs Across Repeated Exposure to Arduino-Based ECP

Paired-samples t-tests were conducted to examine changes in students' motivational beliefs following repeated exposure to Arduino-based experiment-centric instruction. Descriptive and inferential statistics are summarized in Table 1, with pre- and post-intervention mean trends illustrated in Figure 3.

Table 1: Paired-Samples t-Test Results for Changes in Motivational Beliefs

Construct	Pre-test Mean (SD)	Post-test Mean (SD)	Change in Mean	*t* (170)	*p*	Cohen's *d*
Intrinsic Goal Orientation	13.61 (5.36)	16.27 (3.45)	-2.65	−6.03	< .001	0.46
Task Value	13.79 (5.74)	16.63 (4.01)	-2.84	−5.89	< .001	0.45
Self-Efficacy for Learning and Performance	13.11 (6.27)	16.95 (3.64)	-3.84	−7.22	< .001	0.55
Test Anxiety	9.15 (3.91)	9.88 (3.42)	-0.73	−2.03	0.044	0.16

Note: *Negative mean difference = Post scores are higher than Pre scores; This indicates improvement or growth after exposure to Arduino-based ECP. For the reverse-coded test anxiety scale, higher scores indicate lower anxiety.*

As shown in Table 1, statistically significant increases were observed in intrinsic goal orientation, task value, and self-efficacy for learning and performance. Intrinsic goal orientation increased from a pre-intervention mean of 13.61 (SD = 5.36) to a post-intervention mean of 16.27 (SD = 3.45), yielding a significant mean difference ($t(170) = -6.03$, $p < .001$, $d = 0.46$). Task value increased from 13.79 (SD = 5.74) to 16.63 (SD = 4.01) ($t(170) = -5.89$, $p < .001$, $d = 0.45$).

Self-efficacy for learning and performance exhibited the largest change, increasing from a mean of 13.11 (SD = 6.27) to 16.95 (SD = 3.64). This increase was statistically significant ($t(170) = -7.22$, $p < .001$) and associated with a moderate-to-large effect size ($d = 0.55$).

Because the test anxiety subscale was reverse coded, the statistically significant increase from 9.15 (SD = 3.91) to 9.88 (SD = 3.42) ($t(170) = -2.03$, $p = .044$, $d = 0.16$) reflects a small reduction in students' test anxiety.

5.2 Evolution of Self-Regulated Learning Behaviors Over Time

Changes in students' self-regulated learning behaviors were examined using paired-samples *t*-tests on selected learning strategy subscales of the Motivated Strategies for Learning Questionnaire. Results are summarized in Table 2, with corresponding mean trends illustrated in Figure 3.

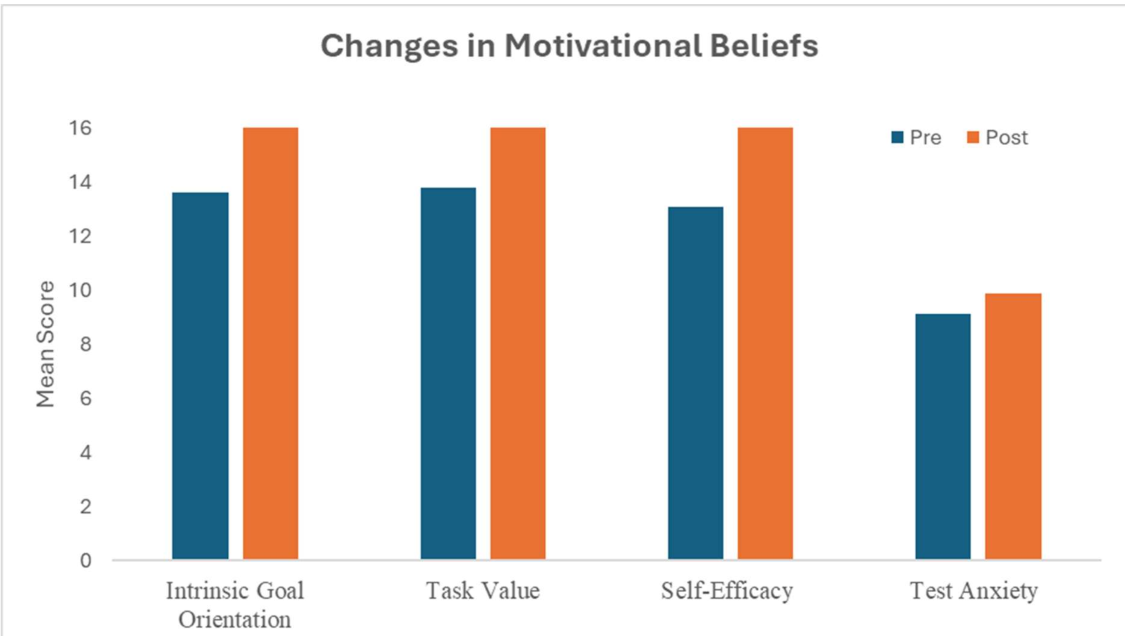

Figure 3: Pre-to-post Changes across Motivational Constructs

Figure 3 shows consistent increases in intrinsic goal orientation, task value, and self-efficacy following exposure to Arduino-based ECP.

As shown in Table 2, statistically significant increases were observed in critical thinking, metacognitive self-regulation, effort regulation, and deep engagement. Critical thinking increased from a pre-intervention mean of 12.80 (SD = 4.35) to a post-intervention mean of 15.29 (SD = 3.56) ($t(170) = -6.32$, $p < .001$, $d = 0.48$).

Metacognitive self-regulation demonstrated the largest effect among self-regulated learning constructs, increasing from 17.47 (SD = 7.04) to 21.75 (SD = 4.58) ($t(170) = -7.99$, $p < .001$, $d = 0.61$).

Table 2: Paired-Samples t-Test Results for Changes in Self-Regulated Learning Behaviors

Construct	Pre-test Mean (SD)	Post-test Mean (SD)	Mean difference	*t*(170)	*p*	Cohen's *d*
Critical Thinking	12.80 (4.35)	15.29 (3.56)	-2.5	−6.32	< .001	0.48
Metacognitive Self-Regulation	17.47 (7.04)	21.75 (4.58)	-4.28	−7.99	< .001	0.61
Planning and Learning Control	13.49 (5.11)	13.92 (5.01)	-0.43	−0.93	0.356	0.07
Effort Regulation	13.42 (5.22)	15.49 (4.31)	-2.07	−4.57	< .001	0.35
Deep Engagement	12.77 (4.05)	14.43 (5.26)	-1.67	−3.75	< .001	0.29

Note. No statistically significant change was observed for planning and learning control.

Effort regulation increased from 13.42 (SD = 5.22) to 15.49 (SD = 4.31) ($t(170) = -4.57$, $p < .001$, $d = 0.35$), while deep engagement increased from 12.77 (SD = 4.05) to 14.43 (SD = 5.26) ($t(170) = -3.75$, $p < .001$, $d = 0.29$).

No statistically significant change was observed for planning and learning control ($t(170) = -0.93$, $p = .356$, $d = 0.07$).

5.3 Classroom Engagement and Outcome Attainment Using COPUS-Aligned Assessment

Classroom engagement and learning outcomes were examined using an outcome assessment aligned with experiment-centric instructional objectives. Student performance across eight learning outcomes was categorized as Unsatisfactory, Developing, Satisfactory, or Exemplary, with a program-level target threshold used as a benchmark for acceptable attainment. Results are presented in Figure 5.

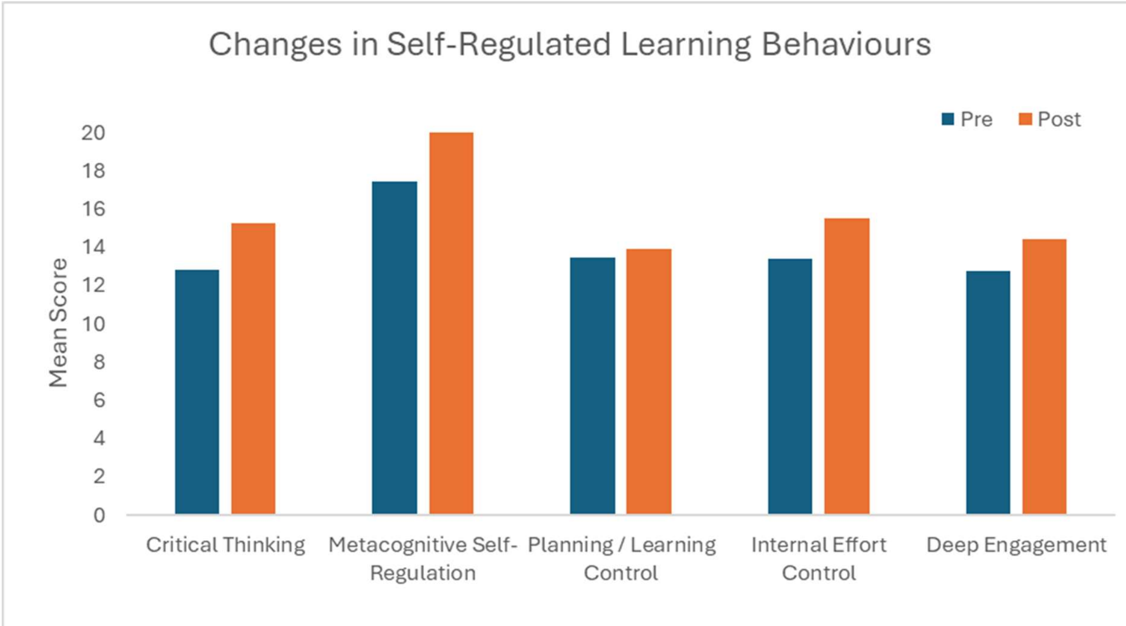

Figure 4: Pre–Post Changes in Self-Regulated Learning Behaviors

Figure 4 highlights particularly pronounced gains in metacognitive self-regulation.

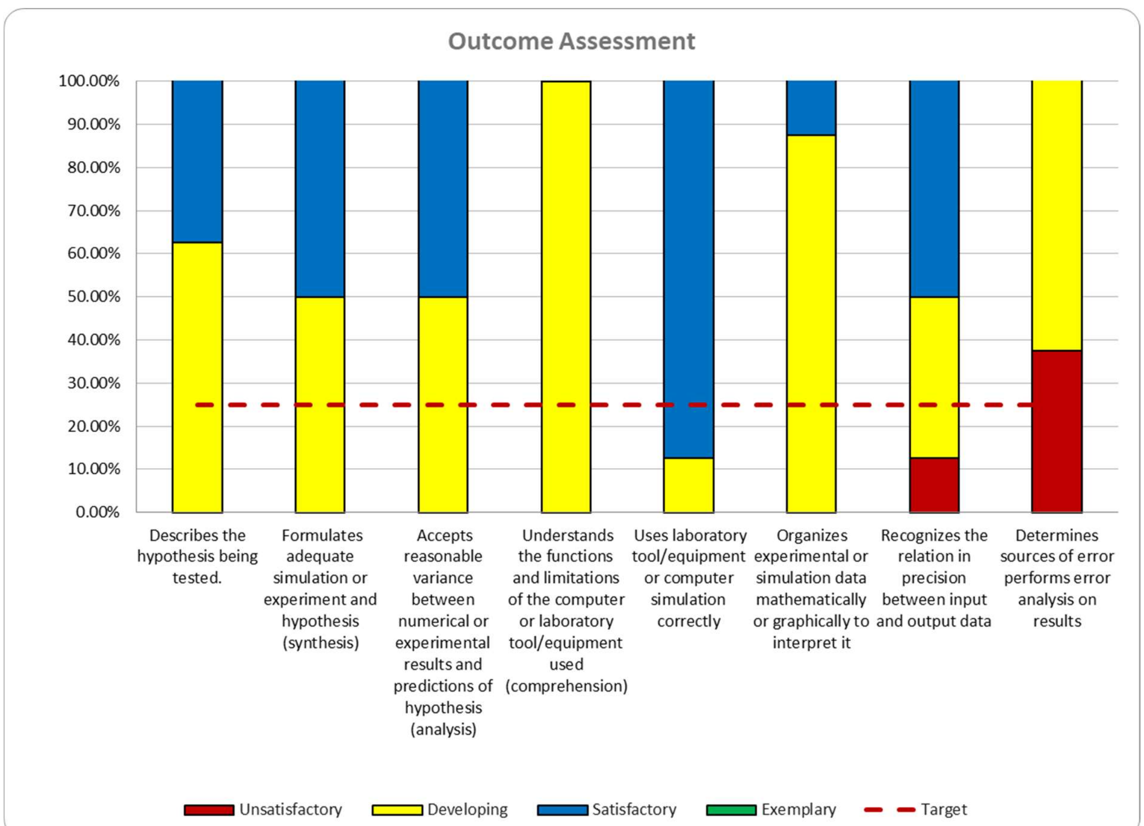

Figure 5: Result of Outcome Assessment in one of the classes

As shown in Figure 5, the combined proportion of students achieving Satisfactory or Exemplary performance exceeded the target threshold for most outcomes. Strong attainment was observed for outcomes related to describing hypotheses, formulating experiments or simulations, interpreting experimental or simulation data, and using laboratory tools or computer simulations correctly.

Outcomes associated with recognizing relationships between inputs and outputs and organizing experimental data graphically or mathematically also demonstrated favorable attainment patterns. In contrast, outcomes related to identifying sources of error and performing error analysis showed a higher proportion of students in the Developing category.

6. Discussion

This study examined how sustained exposure to Arduino-based Experimental-Centric Pedagogy influenced students' motivation, self-regulated learning behaviors, and classroom engagement in Civil and Transportation Engineering courses at an HBCU. The findings extend prior research on experiment-centric instruction by providing longitudinal evidence of cumulative motivational and cognitive effects across multiple academic terms.

The observed increases in intrinsic goal orientation, task value, and self-efficacy are consistent with prior studies reporting motivational gains associated with hands-on and experiment-centric pedagogies [1] [4]. Notably, the magnitude of self-efficacy gains aligns with findings reported by Ige et al., [6], suggesting that repeated experiential engagement supports confidence development in civil engineering contexts. The longitudinal nature of the present study extends the work of [5] by demonstrating that motivational gains persist beyond a single course or semester.

The development of metacognitive self-regulation and effort regulation further suggests that experiment-centric instruction supported students' ability to monitor, adapt, and persist through challenging learning tasks. These findings align with self-regulated learning theory, which emphasizes the role of reflective monitoring and sustained effort in complex learning environments [15], [22]. The absence of significant change in planning behaviors mirrors patterns observed in other structured laboratory contexts, where instructional scaffolding limits opportunities for autonomous planning [18].

Outcome assessment results provide observable evidence that motivational and self-regulatory gains translated into performance-based learning outcomes. Strong attainment in outcomes related to experimentation, data interpretation, and tool usage is consistent with prior COPUS-based studies linking active instructional practices to increased student engagement [18]. More modest performance in error analysis outcomes reflects the developmental complexity of evaluative reasoning and supports calls for sustained emphasis on uncertainty analysis in engineering curricula [14].

These findings contribute to a growing body of evidence highlighting the role of pedagogical innovation in fostering persistence, confidence, and engagement among students historically underrepresented in engineering [10], [11].

Limitations

First, this study did not include a non-ECP comparison group or pre-implementation MSLQ data from prior cohorts, thereby limiting the strength of causal inferences attributable solely to Arduino-based Experimental-Centric Pedagogy for the observed improvements in motivation and self-regulation. The findings thus provide evidence of associations between sustained ECP exposure and favorable trends in these motivational and self-regulated learning constructs within the specific institutional context examined.

Second, the research was confined to a single HBCU civil and transportation engineering program, which constrains generalizability across other institutional types, disciplines, or student demographics. Future investigations should incorporate comparisons between HBCU and non-HBCU settings, as well as parallel non-ECP course sections, to elucidate how institutional contexts and pedagogical approaches interactively influence motivational development over time.

Because the Arduino-based laboratory activities were highly structured and instructor-scaffolded, students had limited opportunities to independently plan their learning, which may contribute to the non-significant change observed for planning and learning control.

Future iterations will include explicit error-analysis mini-activities and rubric criteria to more deliberately target evaluative reasoning outcomes.

Conclusion

This study investigated the longitudinal effects of Arduino-based Experimental-Centric Pedagogy on student motivation, self-regulated learning, and classroom engagement in Civil and Transportation Engineering courses at a historically Black college and university. Quantitative analyses indicated statistically significant improvements in intrinsic goal orientation, task value, and self-efficacy for learning and performance, along with a reduction in test anxiety following repeated exposure to experimental-centric instruction. Gains were also observed in several dimensions of self-regulated learning, including metacognitive self-regulation, effort regulation, and deep engagement, suggesting enhanced student capacity to monitor and sustain learning over time. Classroom observations and outcome assessments further indicated increased active engagement and improved attainment of course-level learning objectives. Anchored in Kolb's Experiential Learning Theory, the integration of Arduino and ADALM2000 supported structured cycles of experimentation, reflection, and conceptual understanding. In summary, the findings provide empirical support for the use of Arduino-based Experimental-Centric Pedagogy as an effective instructional approach in undergraduate civil and transportation engineering education.

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